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# Sheldahl

Advanced Products Division

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## INVESTIGATION OF KEVLAR FABRIC BASED MATERIALS FOR USE WITH INFLATABLE STRUCTURES

by R. J. Niccum and J. B. Munson

Sheldahl Company

APRIL 1974

Prepared for Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, D. C.

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Langley Station, Hampton, Virginia

## FOREWORD

This report was prepared by personnel of Sheldahl, Northfield, Minnesota, under NASA Contract NAS1-11694 and is based upon work performed between June 1972 and June 1973 by the contractor. The work was directed and monitored by the NASA Langley Research Center under the technical direction of Mr. V.L. Alley, Jr., of the Directorate for Engineering and Operations and Mr. Austin Mellatton, the Technical Representative of the Contracting Offices, Systems Engineering Division. Funds for this research were provided NASA by the Advanced Research Planning Agency (ARPA) of the Department of Defense.

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## ABSTRACT

Although tethered balloons have been in use for over a century, the past decade has produced the greatest increase in the sophistication and complexity of these vehicles and considerable related technology has evolved. Recently developed, high-strength materials for hulls, fins and rigging have made a major contribution to improved windward performance. The new DuPont organic fiber, Kevlar\*, offers further performance gains. Design, manufacture and testing of laminated and coated composite materials incorporating a structural matrix of Kevlar is reported in detail. The practicality of using Kevlar in aerostat materials is demonstrated and data are provided on practical weaves, lamination and coating particulars, rigidity, strength, weight, elastic coefficients, abrasion resistance, crease effects, peel strength, blocking tendencies, helium permeability, and fabrication techniques. Properties of the Kevlar based materials are compared with conventional, Dacron\* reinforced counterparts. A comprehensive test and qualification program is discussed and considerable quantitative biaxial tensile and shear test data are provided. The investigation shows that single ply laminates of Kevlar and plastic films offer significant strength to weight improvements, are less permeable than two ply coated materials, but have a lower flex life. Creasing causes a significant loss in strength for Kevlar laminates. Further research is proposed to reduce the inherent rigidity of the experimental laminate material. Multiaxial textile constructions of Kevlar such as triaxial weaves or parallel, nonwoven yarn arrays laminated to film gas barriers appear to be potential fabrication techniques of considerable merit.

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## 1.0 INTRODUCTION

Tethered balloons have been in existence for over a century. They were used in the Civil War as a platform from which field artillery observers could direct fire. During the Second World War, England used them rather extensively as a protection against the aircraft threat. In spite of this long history, the technologies for these vehicles has remained largely undeveloped until recent years. Consequently, these vehicles were quite unreliable and never gained widespread usage. In the past decade, however, improvements in materials, the increased content and scope of aerodynamics research, and the ability to perform complex structural and stability analyses by automated methods has permitted engineers to review these devices as potentially serviceable and useful systems. The extent of evolution and improvement in these vehicles can be seen by observing Figures 1 through 4.

Figure 1 shows an early version of the barrage balloon. The material was essentially a cotton structural fabric with neoprene outer coating and neoprene between the structural fabric and the bias ply fabric. Its strength was about 17,500 newtons per meter (one hundred pounds per inch), and its helium permeability was high. This material proved quite durable, however. The cleaning, priming, and bonding operations for making joints were extremely time consuming and costly. The flaccid shape resulted from the fact that the ballonnet was inflated by air scoops so the hull was non-rigid in the absence of wind.

Figure 2 shows an improved version of the early barrage balloon that used a more advanced nylon structural material. This material was .034 kilograms per square meter (one ounce per square yard) lighter than its predecessor, about 30% stronger and had a lower permeability. The rigidity of the vehicle at low wind speeds was improved by the addition of electrically powered blowers.

Figure 3 shows the initial version of the "Family II" shape tethered aerostat. This configuration was rigorously tested in a wind tunnel to investigate the various stability effects of fin size and locations, center of gravity locations, confluence position, etc. The material in this balloon was of conventional coated fabric, but high tenacity Dacron\* instead of nylon was used for bias and structural ply fabrics yielding a nearly isotropic material of approximately 26,250 newtons per meter (150 pounds per inch) ultimate membrane strength in both the warp and fill direction.

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A. EARLY BARRAGE BALLOON

**B. MATERIAL PROPERTIES(HULL)**

WEIGHT	-----	$\frac{\text{kg/m}^2 \text{ (OZ/YD}^2\text{)}}{406 \quad (12)}$
TENSILE		
WARP	-----	$\frac{\text{N/m (LBS/IN)}}{20,650 \quad (118)}$
FILL	-----	18,375 (105)
COATING ADHESION	-----	?
PLY ADHESION	-----	?
HELIUM PERMEABILITY	-----	2.5 (1 /m <sup>2</sup> /24 hrs)

**C. MATERIAL CONSTRUCTION (HULL)**

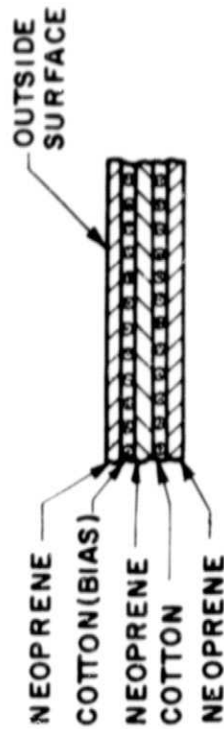
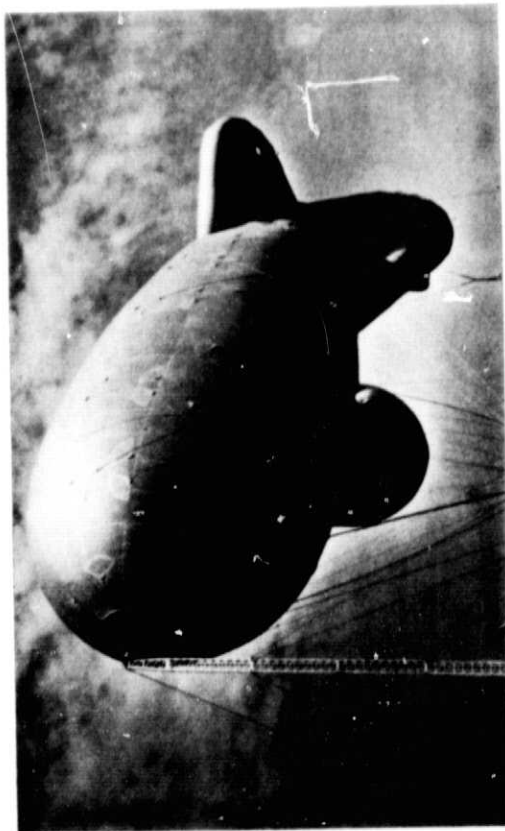


FIGURE I.--EARLY TETHERED BALLOON DESIGN



A. MODIFIED BARRAGE BALLOON

B. MATERIAL PROPERTIES (HULL)

WEIGHT -----  $\frac{\text{kg/m}^2 \text{ (OZ/YD}^2\text{)}}{.376 \quad (11.06)}$

TENSILE

WARP -----  $\frac{\text{N/m (LBS/IN)}}{22,400 \text{ (128)}}$

FILL ----- 23,975 (137)

COATING ADHESION ---- 1,225 (7)

PLY ADHESION ----- 2,450 (14)

HELIUM PERMEABILITY ---- 2.0  
(1 /m<sup>2</sup> /24 hrs )

C. MATERIAL CONSTRUCTION (HULL)

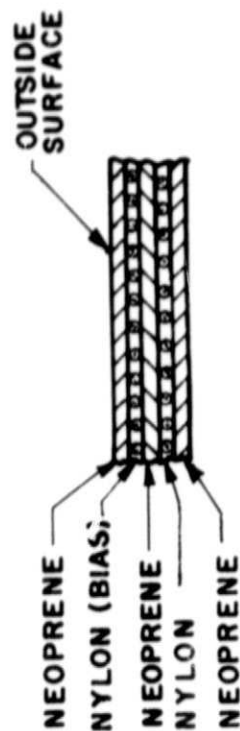


FIGURE 2.- IMPROVED MATERIAL ON EARLY DESIGN

### B. MATERIAL PROPERTIES (HULL)

WEIGHT -----  $\frac{\text{kg/m}^2}{.439}$   $\frac{\text{OZ/YD}^2}{(12.9)}$

#### TENSILE

WARP -----  $\frac{\text{N/m}}{26,250}$   $\frac{\text{LBS/IN}}{(150)}$

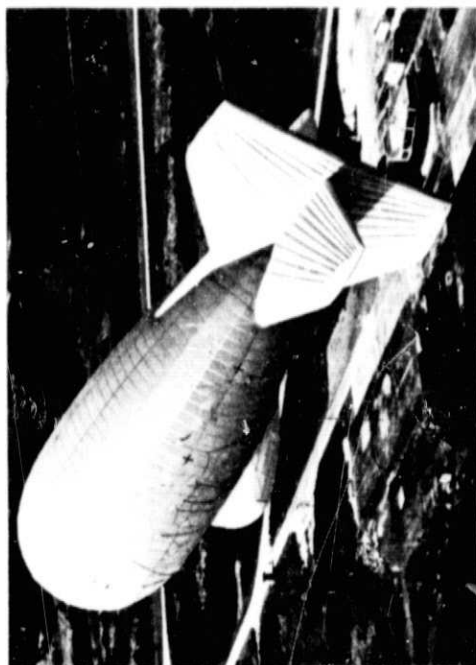
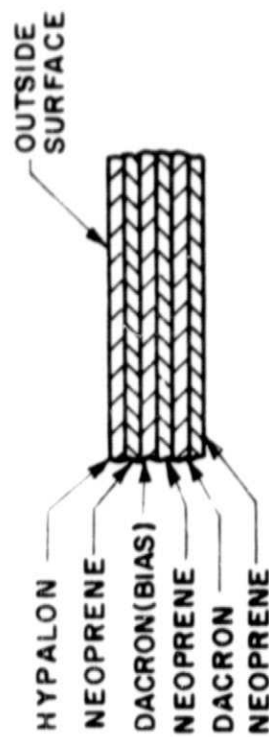
FILL ----- 26,250 (150)

COATING ADHESION \_ 1,225 (7)

PLY ADHESION 787.5 (4.5)

HELIUM PERMEABILITY ----- 2  
(1 / m<sup>2</sup> / 24 hrs )

### C. MATERIAL CONSTRUCTION (HULL)



A. FAMILY II AEROSTAT, CBV-200A, S/N 201

FIGURE 3.- INITIAL FAMILY II TETHERED AEROSTAT DESIGN

Figure 4 shows a system considered to reflect the current state-of-art in aerostat design and manufacturing technique. The major difference between this configuration and the balloon in Figure 3 is a further improvement in material. For a unit weight of only 0.292 kilograms per square meter (8.6 ounces per square yard) the ultimate strength of the material was increased to  $39.4 \times 10^3$  newtons per meter (225 pounds per inch) in both the warp and fill directions. This was accomplished with a composite structure incorporating plastic films of Tedlar\* and Mylar\* laminated to a very strong Dacron fabric. This construction provides a gas barrier with one fourth the permeability of comparable coated fabrics and adequate shear strength for the intended use.

Figure 5 compares the payload capacity for different construction materials of similarly shaped 7,075 cubic meter (250,000 cubic foot) balloons to be operated at 3,048 meter (10,000 ft) altitude. The coated Dacron, two ply materials are used in construction of the aerostat in Figure 3. The Dacron-Mylar-Tedlar laminate was used for the system in Figure 4. The latter permits a saving in vehicle weight of 544 kilograms (1,200 pounds) which is a 57 percent increase in payload capacity over the former coated material. The dramatic effect of material weight on payload capacity has been the motivation for further research on more advanced materials having greater strength to weight ratios, low permeability and high resistance and adaptability to the environment.

Currently, extensive studies are underway in both private industry and Government on the structural use of filamentary materials, particularly the new organic, high strength, high modulus fiber, Kevlar\* recently marketed by DuPont. These fibers, also designated "PRD-49" (Preliminary Research and Development number 49), and "Fiber B", offer strength to weight ratios 2 to  $3\frac{1}{2}$  times that of Dacron, and 10 times that of steel. The strength to weight ratio of Kevlar exceeds that of all other materials which can be fabricated using conventional textile technology.

The general object of the studies reported here was to determine whether or not a practical aerostat material could be manufactured using Kevlar. The particular objectives were to determine weave geometries, lamination process details, and the effects of high fiber rigidity, strength and weight characteristics under uniaxial and biaxial loading, to obtain quantitative material coefficients, and to determine abrasion resistance, crease effects, peel strength, blocking tendency, helium permeability, and joinery techniques. In investigating the mechanical performance of the various materials reported a macroscopic approach has been used and no attempt was made to consider the micromechanics of the composites. Macroscopic data are of primary interest for the materials considered since current technology is essentially limited to use of average performance characteristics and a scarcity of such data is most evident.

A small quantity of two experimental materials and two conventional materials (as controls) was manufactured by Sheldahl, Northfield, Minnesota, to contract specifications and tested by the contractor for the pertinent geometric and mechanical characteristics.

In the following sections the design, construction details, test methods, results and conclusions are discussed in detail.

\* DuPont Registered Trademarks

**B. MATERIAL PROPERTIES (HULL)**

WEIGHT -----  $\frac{\text{kg/m}^2}{.292}$   $\frac{(\text{OZ/YD}^2)}{(8.6)}$

TENSILE  $\frac{\text{N/m}}{39,375}$   $\frac{(\text{LBS/IN})}{(225)}$

WARP ----- 39,375 (225)

FILL ----- 39,375 (225)

**TONGUE TEAR**

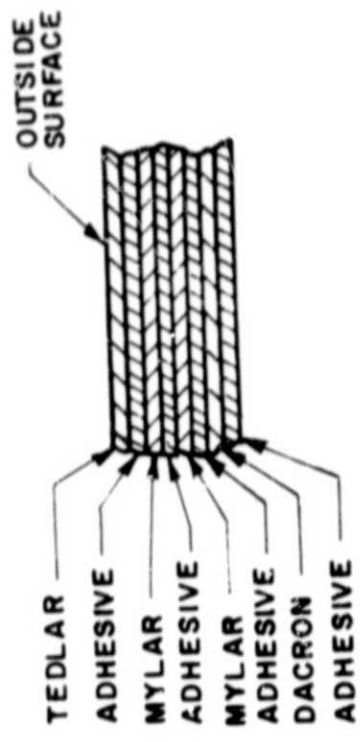
WARP ----- 10,500 (60)

FILL ----- 10,500 (60)

PEEL ----- 1,750 (10)

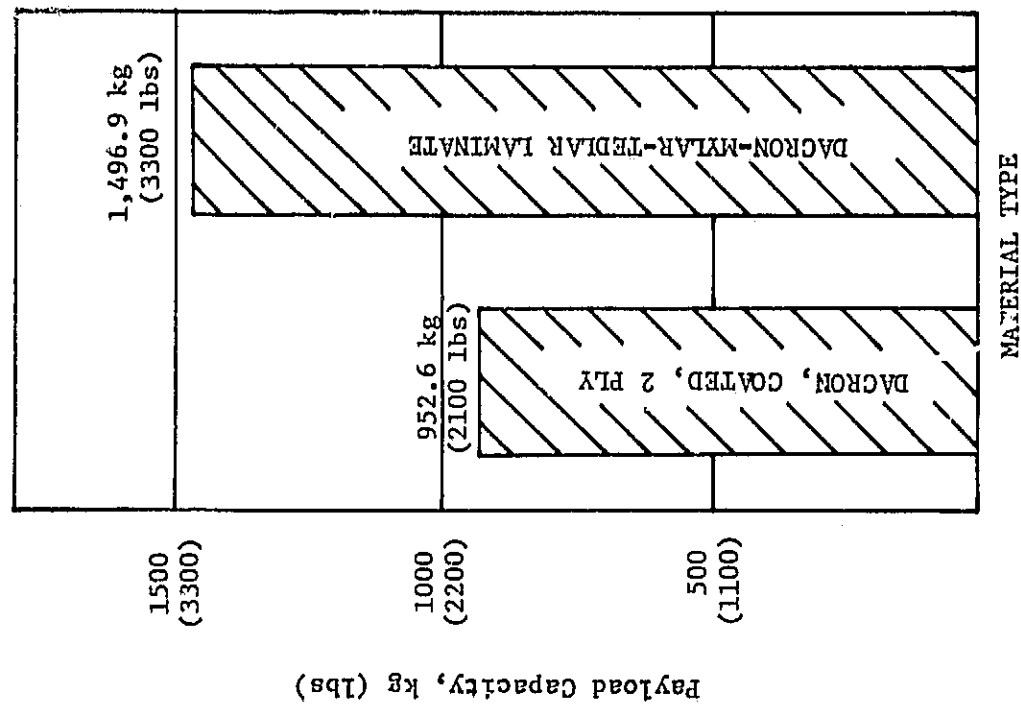
HELIUM PERMEABILITY ----- 0.5  
( $\text{l/m}^2/24 \text{ hrs}$ )

**C. MATERIAL CONSTRUCTION (HULL)**



**A. FAMILY II AEROSTAT, CBV-250A, S/N 101**

**FIGURE 4.-CURRENT STATE-OF-ART TETHERED AEROSTAT DESIGN**



# TYPICAL VEHICLE CHARACTERISTICS

OPERATING ALTITUDE	-	3,048 m above MSL (10,000 ft.)
TETHER WEIGHT		297 kg/1000 m (200 lbs/1000 ft.)
SHAPE		Family II (Hull Type III)
SIZE		7,075 m <sup>3</sup> (250,000 ft <sup>3</sup> )
DESIGN WINDS		36 m/sec. max. (70 knots max.)

FIGURE 5. MATERIALS DEVELOPMENT EFFECT ON PAYLOAD CAPACITY FOR TETHERED AEROSTATS

## 2.0 PREPARATION OF EXPERIMENTAL AND BASELINE MATERIALS

One of the experimental materials was designed as a lamine construction to yield a strength equal to the traditional material but with a reduction in weight. The second material was designed as a coated construction to be equal in weight to its traditional counterpart and to have a higher strength.

The two conventional materials (Figures 3 and 4) were based on a Dacron structural fabric. The two experimental materials employed Kevlar-49 as the structural member. Sufficient quantities of these materials were manufactured to produce flat and cylindrical specimens for testing and were manufactured on conventional production equipment at the Sheldahl plant.

### 2.1 Material Design

Material properties which may be of concern to the balloon envelope designer are:

Mechanical Strength (under tension, tearing, puncture, shear and peel)

Weight

Permeability (to lifting gases)

Environmental Strength (resistance to solar-ultraviolet degradation and relative immunity to temperature extremes and effects of moisture)

Efficiency of Seams (between panels of the material)

Handling Strength (resistance to abrasion and degradation from folding, creasing and other effects of handling, particularly when the balloon is in a flaccid state)

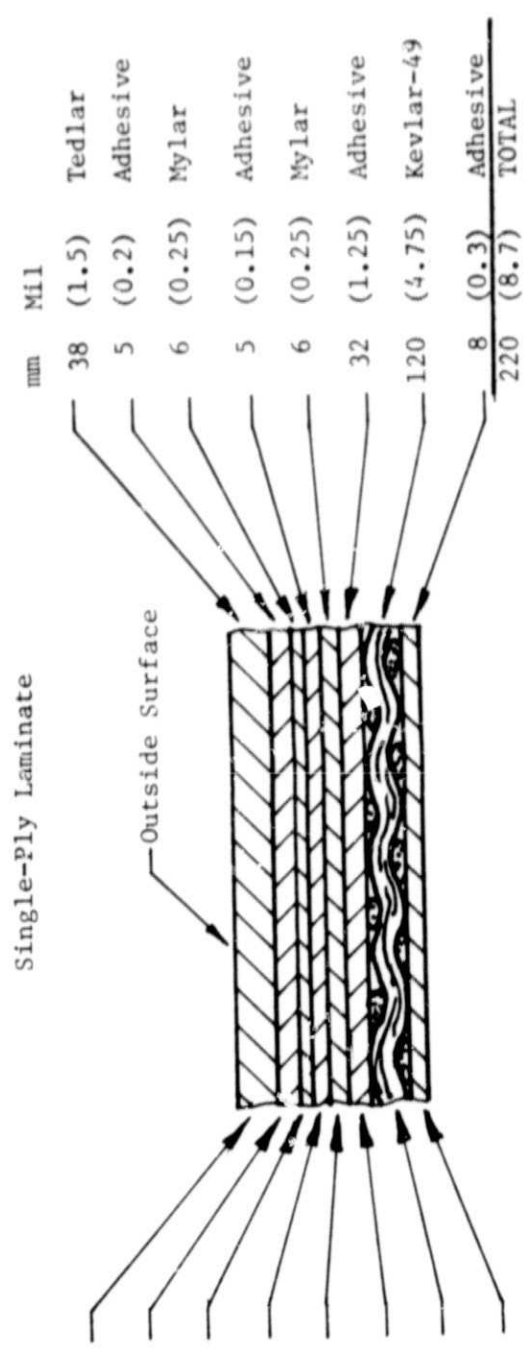
Special Requirements (radar reflectivity, nuclear "hardness", etc. peculiar to a balloon application)

Cost (of blank material and of seaming method)

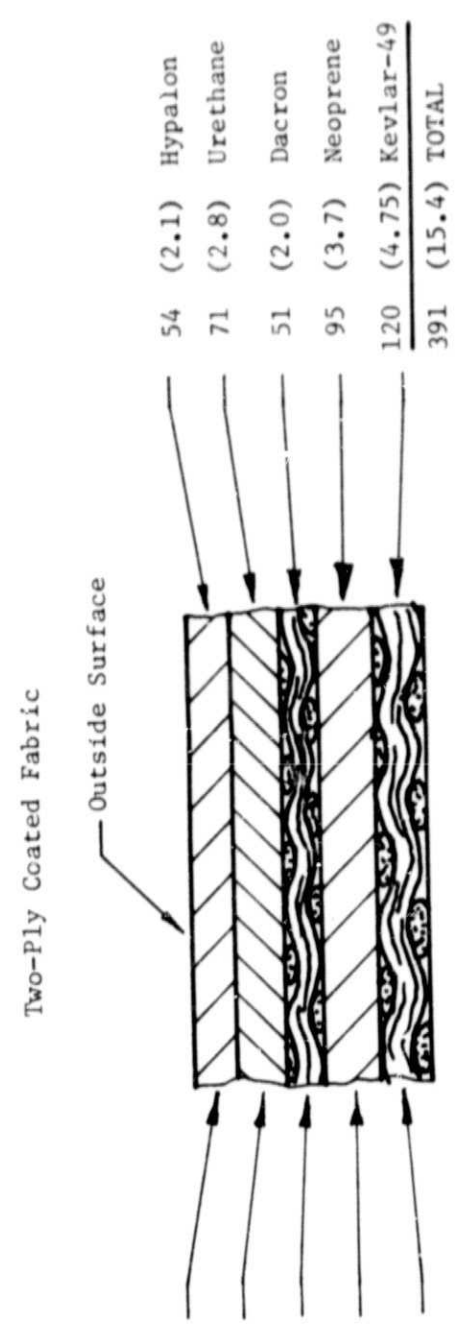
The designers problem is to formulate a functional composite of fabrics, films, adhesives and coatings to obtain an optimum balance of the above properties for a given application.

Figure 6 shows cross sections of the experimental single ply laminate and the experimental two ply coated construction. The design concept of construction is indicated on the left of the figure and the actual construction incorporating necessary compromises is shown on the right. The corresponding control materials for these two materials are shown similarly in Figures 3 and 4. In order to achieve structural efficiency in fabricating joints from the experimental materials, the structural lattice provided by the Kevlar fabric was positioned near the inner side of the composite. This geometric feature generally increases the rigidity and stiffness of the finished product and inhibits folding, creasing, packaging and flexing. However, it is considered necessary to achieve adequate

Thickness as Constructed



<u>Design Thickness</u>	
mm	Mil
Tedlar 38	(1.5)
Adhesive 5	(0.2)
Mylar 6	(0.25)
Adhesive 5	(0.2)
Mylar 6	(0.25)
Adhesive 18	(0.7)
Kevlar 120	(4.75)
Adhesive 8	(0.3)
TOTAL 206	(8.2)



Hypalon 54	(2.1)
Urethane 56	(2.2)
Dacron 51	(2.0)
Neoprene 82	(3.2)
Kevlar-49 120	(4.75)
TOTAL 363	(14.3)

54	(2.1)	Hypalon
71	(2.8)	Urethane
51	(2.0)	Dacron
95	(3.7)	Neoprene
120	(4.75)	Kevlar-49
391	(15.4)	TOTAL

GEOMETRIC CONFIGURATIONS OF EXPERIMENTAL MATERIALS

FIGURE 6



load transmission between discontinuous yarns at seams. Joining fabric to fabric reduces the thickness of low strength lamina that must transmit shear; it minimizes creep in amorphous viscoelastic lamina, and reduces non-planar deformations. The outer surfaces of the materials are coated with Tedlar or Hypalon to provide a durable, tough, abrasive surface along with ultraviolet (UV) protection for the inner constituents. The Mylar adhesive and Kevlar are susceptible to UV degradation and require protection for applications where exposure to the solar spectrum for extended periods is a mission requirement. The Tedlar filters out more than 98 percent of the incident UV radiation and is not itself significantly degraded by up to twenty years exposure to weathering. To insure low helium permeability, a bi-lamination of Mylar films is employed in the laminate. The multi-application of adhesive coats to facilitate fabrication and provide a finished inside surface along with the outer abrasion-resistant material afford even greater impermeability. The coated material has slightly higher permeability with the gas barrier being provided primarily by the neoprene and urethane membranes. The urethane also provides some UV protection to the lamina fabric.

Since Kevlar became available only recently, the experimental materials were limited to the available yarn deniers and weave geometry. Lamination and coating processes had to be considered since these are affected by the weave. For example, an open weave with wide spacing between yarns is difficult to laminate because of dimensional instability of the fabric prior to combining with the film. In coating operations, open weave fabrics cause "strike through" or bleeding of the coating through the yarn interstices, which adversely affects coating of the opposite side. A close weave minimizes the weight of coating and laminate adhesive, has good dimensional stability during processing, and is amenable to laminating or coating.

Since the ability to form joints by thermal sealing was a design objective for the experimental materials, the use of coating materials like neoprene was eliminated for exterior surfaces. The experimental fabrics were made as similar in configuration to the traditional Dacron fabrics as possible. For the laminate, the construction is identical to the counterpart control material except for substitution of Kevlar for Dacron and changes in the yarn denier and count in the base fabric. For the coated fabric only the main fabric ply was changed from Dacron to Kevlar. Dacron was used for the bias ply in the coated material because no suitable Kevlar yarn denier and weave patterns were available.

Kevlar yarn size was limited to 195 and 380 denier. Because of the requirement for equal warp and fill strength, a square weave pattern was specified.

Although the tear strength of woven Kevlar had not been measured prior to this investigation, it was assumed to be adequate for balloon use due to the high yarn strength. Consequently, a plain weave pattern was used rather than a more complicated basket weave. If it later became necessary to enhance the tear strength, basket weave Kevlar fabric could be substituted.

It was found that the experimental laminate material could be made equal in strength to the standard laminate if the Kevlar fabric weighed approximately .061 kilograms per square meter (1.8 ounces per square yard) which would give about 47,259 newtons per meter (270 pounds per inch) uniaxial strength in both warp and fill directions. For the second coated material, the primary ply

Kevlar fabric was made equal in weight to that of its traditional Dacron counterpart, .095 kilograms per square meter (2.8 ounces per square yard). This was found to have a strength of about 73,500 newtons per meter (420 pounds per inch) in both warp and fill directions.

Properties of the constituent Kevlar fabrics used in the laminate and coated materials are presented in Table 1-A. The actual weights of the fabrics used in the prototype materials were very close to the theoretical weights. The tested strength of the 0.059 kg/m<sup>2</sup> (2.8 oz/yd<sup>2</sup>) fabric was almost exactly as predicted. However, the strength of the 0.061 kg/m<sup>2</sup> (1.8 oz/yd<sup>2</sup>) fabric was slightly lower than the theoretical value. The 0.059 kg/m<sup>2</sup> (2.8 oz/yd<sup>2</sup>) fabric was a conventional weave whereas the 0.061 kg/m<sup>2</sup> (1.8 oz/yd<sup>2</sup>) fabric is a loose weave. The yarn was washed of lubricants to improve adhesion and a low twist of 4 turns per meter (0.1 turn per inch) in the yarn is typical. A low twist yarn yields thin lamina of low abrasive finish. No ripstop features were included in the weave, however, such a modification would increase the tear resistance if so required. The basic mechanical properties of the Dacron fabrics used in the fabrication are given on Table 1-B. The pertinent properties of interest for the constituent membranes used are provided in Table 1-C. These data are for the Tedlar, polyester adhesive, Mylar, Hypalon, Neoprene and Urethane. The adhesive is a significant proportion of the single ply laminate and its properties and performance are important features in the mechanical behavior of the composite structure, primarily at low temperature. A typical environment for materials applications reported here is -34.4° to 45.6°C (-30° to 112°F). The membranes and fibers remain ductile at these temperatures, but the adhesives used become glassy and brittle. This can produce inter-laminar deterioration and premature structural failure from loading at cold temperatures. Parallel research is being conducted at Princeton University to obtain suitable adhesives that will not undergo glassy transitions for temperatures above -67.8°C (-90°F). The status of this research was not sufficiently advanced to permit the use of these experimental adhesives in the materials discussed here.

## 2.2 Lamination Procedure

The experimental laminate and its control material were manufactured in pilot scale quantities on Schjeldahl production laminators, Figure 7.

2.2.1 Equipment. The laminator shown in Figure 7 consists of three parts: an adhesive coating section, a drying section and a combining section. When laminating two materials, one is coated with adhesive and the other becomes the combining material. The material to be coated travels from an unwind station and over a drum rotating in an adhesive bath. The coated ply then travels through a drying tunnel to remove adhesive solvents. It then is joined to the combining material and passes between a pair of rolls which apply sufficient pressure and heat to fuse the adhesive layer between the plies. The product is rewound for storage as the adhesive cools. When combining films the product is simply wound upon itself at the take-up station. Lamination of fabric to films may require the insertion of a release sheet at the take up point to prevent adhesive exposed by the fabric interstices from sticking or transferring to the opposite side of the product. Polyethylene film 12 to 25μ (0.5 to 1.0 mil) thick or silicone treated, 18 kg (40 pound) kraft paper are commonly used for this purpose.

TABLE 1-A

PROPERTIES OF KEVIAR-49 FABRIC COMPONENTS  
Metric Units (English Units in Parentheses)

Application Characteristic	1-Ply Laminate Experimental (Figure 6)	2-Ply Coated Experimental (Figure 6)
Weight	0.060 kg/m <sup>2</sup> (1.8 oz/yd <sup>2</sup> )	0.090 kg/m <sup>2</sup> (2.7 oz/yd <sup>2</sup> )
Strength: Warp	39,400 N/m (225 lb/in)	74,400 N/m (425 lb/in)
Fill	39,400 N/m (225 lb/in)	74,400 N/m (425 lb/in)
Weave Type	Plain	Plain
Fabric Finish	Scoured	Scoured
Yarn Count	13/cm x 13/cm (34/in x 34/in)	20/cm x 20/cm (50/in x 50/in)
Yarn Size	195 Denier	195 Denier
Yarn Twist	4 turns/m (0.1 turn/in)	4 turns/m (0.1 turn/in)
Filament Count	134/yarn	134/yarn
Filament Strength	3620 MN/m <sup>2</sup> (5.25 x 10 <sup>5</sup> lb/in <sup>2</sup> )	3620 MN/m <sup>2</sup> (5.25 x 10 <sup>5</sup> lb/in <sup>2</sup> )
Filament Modulus	131 GN/m <sup>2</sup> (1.9 x 10 <sup>7</sup> lb/in <sup>2</sup> )	131 GN/m <sup>2</sup> (1.9 x 10 <sup>7</sup> lb/in <sup>2</sup> )
Density	1450 kg/m <sup>3</sup> (.052 lb/in <sup>3</sup> )	1450 kg/m <sup>3</sup> (.052 lb/in <sup>3</sup> )

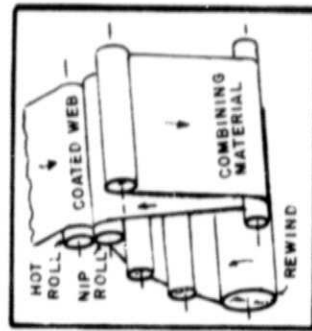
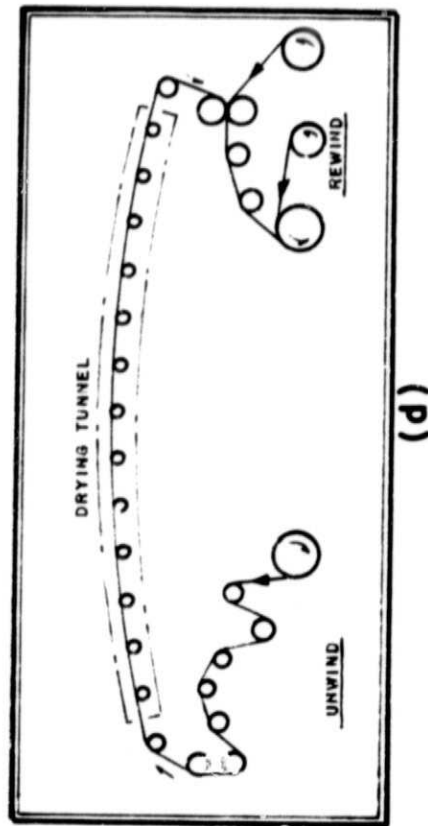
TABLE 1-B  
 PROPERTIES OF DACRON FABRIC COMPONENTS  
 Metric Units (English Units in Parentheses)

Application Characteristic	2-Ply Coated Experimental (Figure 6)	2-Ply Coated Control (Figure 3)	1-Ply Laminate Control (Figure 4)
Weight	0.047 N/m <sup>2</sup> (1.4 oz/yd <sup>2</sup> )	0.108 N/m <sup>2</sup> (3.25 oz/yd <sup>2</sup> )	0.126 N/m <sup>2</sup> (3.8 oz/yd <sup>2</sup> )
Strength: Warp	6,100 N/m (35 lb/in)	27,000 N/m (155 lb/in)	39,400 N/m (225 lb/in)
Fill	6,100 N/m (35 lb/in)	27,000 N/m (155 lb/in)	39,400 N/m (225 lb/in)
Weave Type	Plain	Plain	Plain
Fabric Finish	Scoured and Heat Set	Scoured and Heat Set	Scoured and Weave Set With 5-10% by Weight of Polyvinyl Acetate
Yarn Count	39/cm x 39/cm (98/in x 98/in)	20/cm x 20/cm (50/in x 50/in)	5/cm x 5/cm (13/in x 13/in)
Yarn Size	40 Denier	220 Denier	1,000 Denier
Yarn Twist	9 turns/cm (23 turns/in)	1 turn/cm (3 turns/in)	4 turns/m (0.1 turns/in)
Filament Count	27/yarn	50/yarn	192/yarn
Filament Strength	570 MN/m <sup>2</sup> (0.83 x 10 <sup>5</sup> lb/in <sup>2</sup> )	1030 MN/m <sup>2</sup> (1.5 x 10 <sup>5</sup> lb/in <sup>2</sup> )	1030 MN/m <sup>2</sup> (1.5 x 10 <sup>5</sup> lb/in <sup>2</sup> )
Filament Modulus	13.8 GN/m <sup>2</sup> (2 x 10 <sup>6</sup> lb/in <sup>2</sup> )	13.8 GN/m <sup>2</sup> (2 x 10 <sup>6</sup> lb/in <sup>2</sup> )	13.8 GN/m <sup>2</sup> (2 x 10 <sup>6</sup> lb/in <sup>2</sup> )
Density	1380 kg/m <sup>3</sup> (.05 lb/in <sup>3</sup> )	1380 kg/m <sup>3</sup> (.05 lb/in <sup>3</sup> )	1380 kg/m <sup>3</sup> (.05 lb/in <sup>3</sup> )

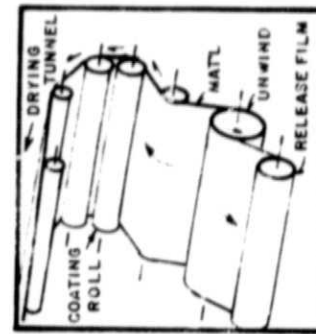
TABLE 1-C

PROPERTIES OF FILM, ADHESIVE, AND COATING COMPONENTS  
Metric Units (English Units in Parentheses)

Characteristic Component	Application	Description	Tensile Strength @ 23°C (70°F)	Density
Tedlar	1-Ply Laminate Control - Fig. 4 and Experimental - Fig. 6	DuPont polyvinylidene fluoride film, type 30, adhereable both sides, "L" gloss, titanium dioxide pigment	55 MN/m <sup>2</sup> (8000 lbs/in <sup>2</sup> )	1770 kg/m <sup>3</sup> (.064 lbs/in <sup>3</sup> )
Mylar	1-Ply Laminate Control - Fig. 4 and Experimental - Fig. 6	DuPont type S, polyester film, 0.25 mil thick	138 MN/m <sup>2</sup> (20,000 lbs/in <sup>2</sup> )	1390 kg/m <sup>3</sup> (.05 lbs/in <sup>3</sup> )
Adhesive	1-Ply Laminate Control - Fig. 4 and Experimental - Fig. 6	Aliphatic polyester resin cured with di-isocyanate for hydrolytic stability	10 MN/m <sup>2</sup> (1500 lbs/in <sup>2</sup> )	1240 kg/m <sup>3</sup> (.045 lbs/in <sup>3</sup> )
Hypalon	2-Ply Coated Control - Fig. 3 and Experimental - Fig. 6	Chlorosulfonated polyethylene with aluminum pigment ----- Chlorosulfonated polyethylene with titanium dioxide pigment	14 MN/m <sup>2</sup> (2000 lbs/in <sup>2</sup> ) ----- 14 MN/m <sup>2</sup> (2000 lbs/in <sup>2</sup> )	1390 kg/m <sup>3</sup> (.05 lbs/in <sup>3</sup> ) ----- 1250 kg/m <sup>3</sup> (.045 lbs/in <sup>3</sup> )
Neoprene	2-Ply Coated Control - Fig. 3 and Experimental - Fig. 6	Low, temperature, non-crystalline polychloroprene with lead cure system for hydrolytic-stability	24 MN/m <sup>2</sup> (3500 lbs/in <sup>2</sup> )	1250 kg/m <sup>3</sup> (.045 lbs/in <sup>3</sup> )
Urethane	2-Ply Coated Experimental - Fig. 6	B. F. Goodrich Estane 5740-X210 low temperature polyurethane formulated for high hydrolytic stability, ultraviolet resistance and heat sealability. Carbon black pigment. Fabric surfaces to be coated are treated with isocyanate type primer.	34 MN/m <sup>2</sup> (5000 lbs/in <sup>2</sup> )	1200 kg/m <sup>3</sup> (.043 lbs/in <sup>3</sup> )



(b) COMBINING END



(e) COATING END

FIGURE 7.- 64 INCH LAMINATOR

2.2.2 Lamination sequence. - In the case of the laminates, the aliphatic, polyester adhesive is applied as an 8 percent solids solution in methylene chloride. Because the resin and cure agent are dispersed, the solution has a pot life of approximately 8 hours. Water may react with the cure agent before the agent acts on the resin producing a structurally inferior product. The following must be religiously observed to minimize H<sub>2</sub>O contamination:

- . Cure agent is stored in air tight containers and dispensed by introducing dry nitrogen gas into the containers.
- . Solvent grades having a low water content are procured and stored in tanks designed to prevent accumulation of water condensate.
- . Exposure of adhesive solution to air having a high relative humidity is avoided as far as possible.
- . Reverse coating rolls and other conductive metal parts of the adhesive handling system which cool by solvent evaporation must be heated above the dew point of the air in the coating room.

Single ply laminates were assembled by applying the adhesive solution to one layer of Mylar with a reverse roll coater, extracting the solvent in a drying tunnel and immediately laminating the coated sheet to the Tedlar film. The other Mylar layer was then coated and bonded to the previous laminate. Finally, the three film laminate was coated and laminated to the fabric. A final pass applied a primer coat of adhesive to the fabric side.

2.2.3 Handling. - Requirements for handling the various layers are equally important to the process result. Since all the plastic films had been used previously in the conventional laminate material, the only new constituent was the Kevlar fabric. The low elongation of Kevlar results in a fabric easily guided by the laminator web handling equipment. A minimum differential deformation was required between the film and the fabric. Deformation, flatness and alignment were well within normal specifications. The final laminate was extremely stable and easy to handle. Since a satisfactory product was so easily achieved, it is believed that no particular problems would arise in the event large scale production was required for this laminate.

## 2.3 Coating Procedure

The coating process was performed by the Haartz Mason Company as a sub-contractor to Sheldahl. Sheldahl representatives were in attendance at the sub-contractor's plant during the coating and combining of the constituents.

2.3.1 Coating process. - Coating equipment consists of mixing machines for the various coating compounds and machines for applying these compounds to fabrics. Commonly, a knife-over-roll process is used which restricts the amount of coating which can be applied on each pass. The fabric first passes the knife-over-roll coater, then travels through a drying tunnel to remove solvents. The dried coated material is rewound and the process repeated as many times as required to achieve the desired coating thickness.

For the experimental fabric described, 0.048 kg/m<sup>2</sup> (1.4 oz/yd<sup>2</sup>) Dacron was coated with neoprene and cut into rhombus shapes at 45° to the warp direction. These segments are rotated to place warp and fill at 45° to the machine direction (biasing) and joined at their edges. The Kevlar was then coated with neoprene and combined with the Dacron bias ply by a process called doubling - Neoprene side to Neoprene side. The Dacron side was coated first with urethane and then with hypalon. The product was trimmed to desired width and wound for storage and transit.

**23.2 Handling-** Dimensional stability of the Dacron bias ply was very poor due to its light weight. Strike through of the coating material to the opposite side of the fabric was difficult to control. Due to the difference in modulus of the Dacron bias and Kevlar primary plies and to the coarseness of the automated web guiding equipment it was virtually impossible to eliminate wrinkling of the plies.

Several process changes would be required before large scale production of coated materials with a Kevlar primary ply would be practical. To improve the operation, the vendor proposed decreasing the yarn count in the Kevlar fabric and using .061 kilograms per square meter (1.8 ounces per square yard) Dacron fabric for the bias ply to add stability to the bias and reduce stability in the Kevlar to make the two materials more compatible. Another alternative would be to use Kevlar for both bias and primary plies. Kevlar yarn in deniers smaller than currently available would be required to make this practical.

### 3.0 TEST PROGRAM

A comprehensive test program was performed on the two experimental materials and the two conventional controls to determine their strength and durability. Tests of uniaxial and biaxial strength, inter-laminar peel strength, crease degradation, blocking, tear strength, abrasion, flexibility and permeability were also performed. The test procedures and test equipment are discussed in the following paragraphs.

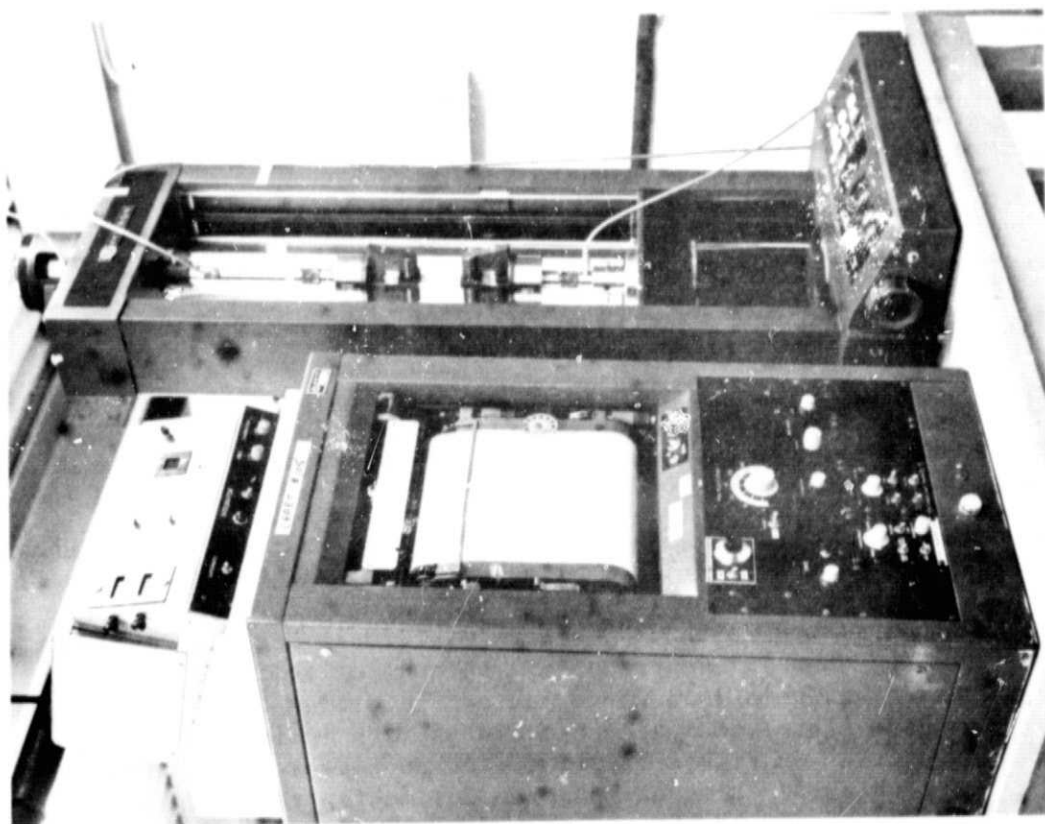
#### 3.1 Strength Tests

Ultimate tensile strength and elastic properties were determined by uniaxial and biaxial testing. Inter-laminar bond strength was investigated by peel tests.

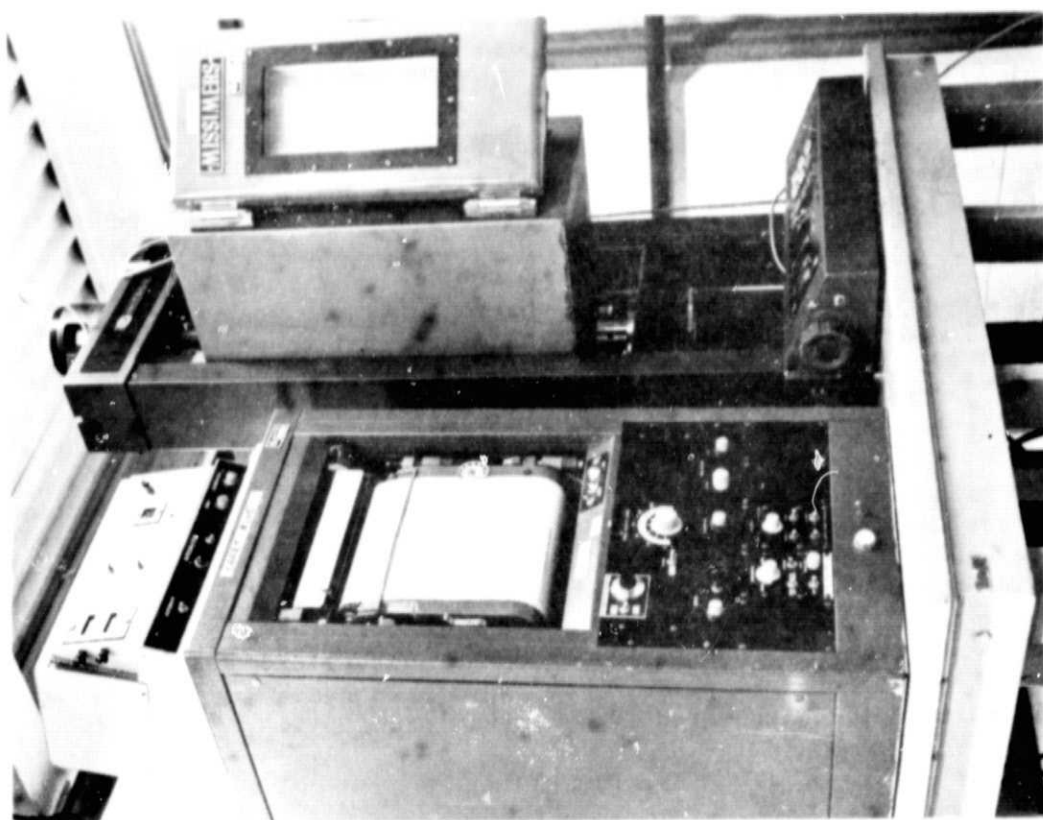
**3.1.1 Uniaxial tensile tests.-** The uniaxial or two dimensional tensile tests conducted on these fabrics are performed using Federal Test Method 5102 which employs a sample size .025 meter (1 inch) wide and a .076 meter (3 inches) grip separation. The grip separation rate for these tests is .305 meter (12 inches) per minute. Five specimens for each test condition were used as a sample population. Test temperatures were 60°C, 22°C and -51°C (140°F, 72°F and -60°F).

All tests were conducted using a Model 114 Instron Testing Machine shown in Figure 8. This machine has a capacity of 4,448 newtons (1,000 pounds), variable strain rates up to 1.27 meters/min (50 inches/min) for loads up to 2,224 newtons (500 pounds) and up to .508 meters/min (20 inches/min) at loads up to 4,448 newtons (1,000 pounds). Accuracy is 1 percent of full scale reading. The chart readout has a variable load range and can be driven to 1.27 meters/min (50 in/min) paper speed. This model also has dial strain indicators and sample break and slope detectors. On Figure 8(a) the Instron tester is shown without the environmental chamber which is the configuration for making room temperature tests. Figure 8(b) shows the Instron with the environmental chamber attached for testing at elevated and sub-zero temperatures.





AMBIENT TEMPERATURE TEST ARRANGEMENT  
(a)



VARIABLE TEMPERATURE TEST ARRANGEMENT  
(b)

FIGURE 8.- INSTRON TENSILE TEST FACILITY



**Schjeldahl** / ADVANCED PROGRAMS DIVISION

G. T. SCHJELDAHL COMPANY • NORTHFIELD, MINNESOTA 55057 • PHONE 507-645-5633

VIA AIR MAIL

16 May 1974

National Aeronautics and Space Administration  
Scientific and Technical Information Facility  
Post Office Box 33  
College Park, Maryland 20740

Subject: Contract NAS1-11694, Final Report  
Reproducible Copy

Gentlemen:

Enclosed herewith is the reproducible copy of the Final Report, NASA CR-132411, entitled, "Investigation of Kevlar Fabric Based Materials for use with Inflatable Structures," by R. J. Niccum and J. B. Munson. This was inadvertently not included with the shipment of twelve printed copies that were forwarded to your office on 10 May 1974 via Parcel Post mail pursuant to the Contracting Officer's distribution list instructions.

We regret any inconvenience this separate mailing may cause you.

Sincerely,

J. A. Torrey  
Deputy Director of Administration

pp  
Enclosures

cc: Mr. C. Ray Davis, Contracting Officer, NASA Langley, w/o enc.



For the laminates, tests were conducted on the finished materials as well as on the various film plies which comprise the gas barrier and outer surface. Figures 9 and 10 show sample preparation methods, sample mounting techniques, and typical charts.

The Thwing-Albert sample cutter shown in Figure 9 provides a uniform, precision sample width of 25.4 mm. One cutter was used for thin film specimens and a separate cutter used for the heavier fabric based specimens to preserve the quality of cut edges on the thin film specimens.

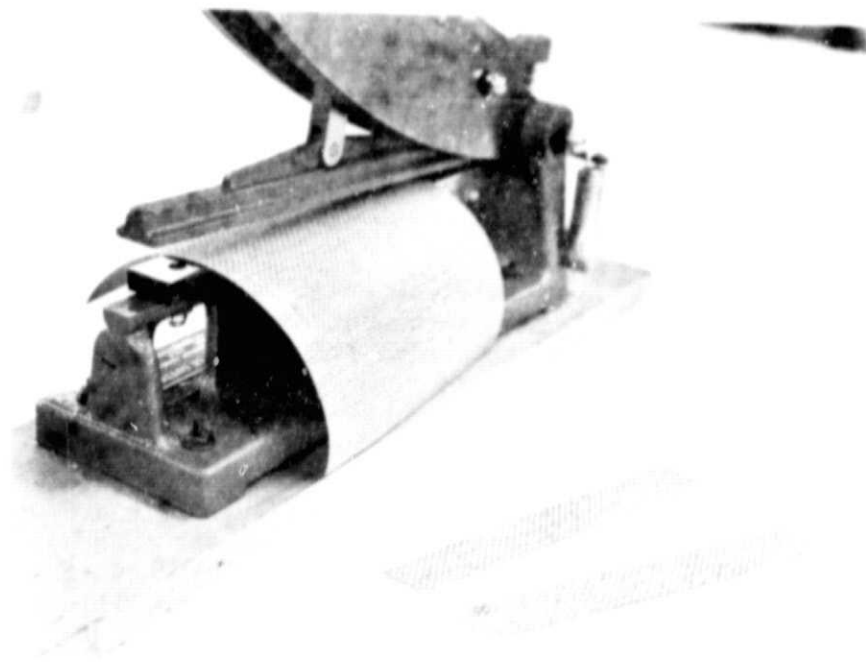
Typical samples of untested and failed specimens of finished materials are shown in Figure 10 along with a specimen mounted in the Instron jaws ready for testing. A chart recording displayed in Figure 10(c) shows the typical stress strain relationship to failure for each of the four materials tested. The difference in grip travel between the two Kevlar based materials and the Dacron based materials indicates the low elongation to failure of Kevlar.

Generally, uniaxial coupon tests are not a reliable indication of material strength. This is particularly true for composites having diagonal or bias structural elements. In addition, for woven fabrics, the stability of the weave, crimp, and yarn interlock effects are degraded in the one dimensional stress field. However, the uniaxial test is a simple fast and inexpensive method adequate as an indication of strength and anisotropy and as a quality control procedure. The deficiency of uniaxial coupon tests to fully involve and stress the structural features of laminated fabric materials has been the motivation for more sophisticated two-dimensional biaxial testing by the cylinder method.

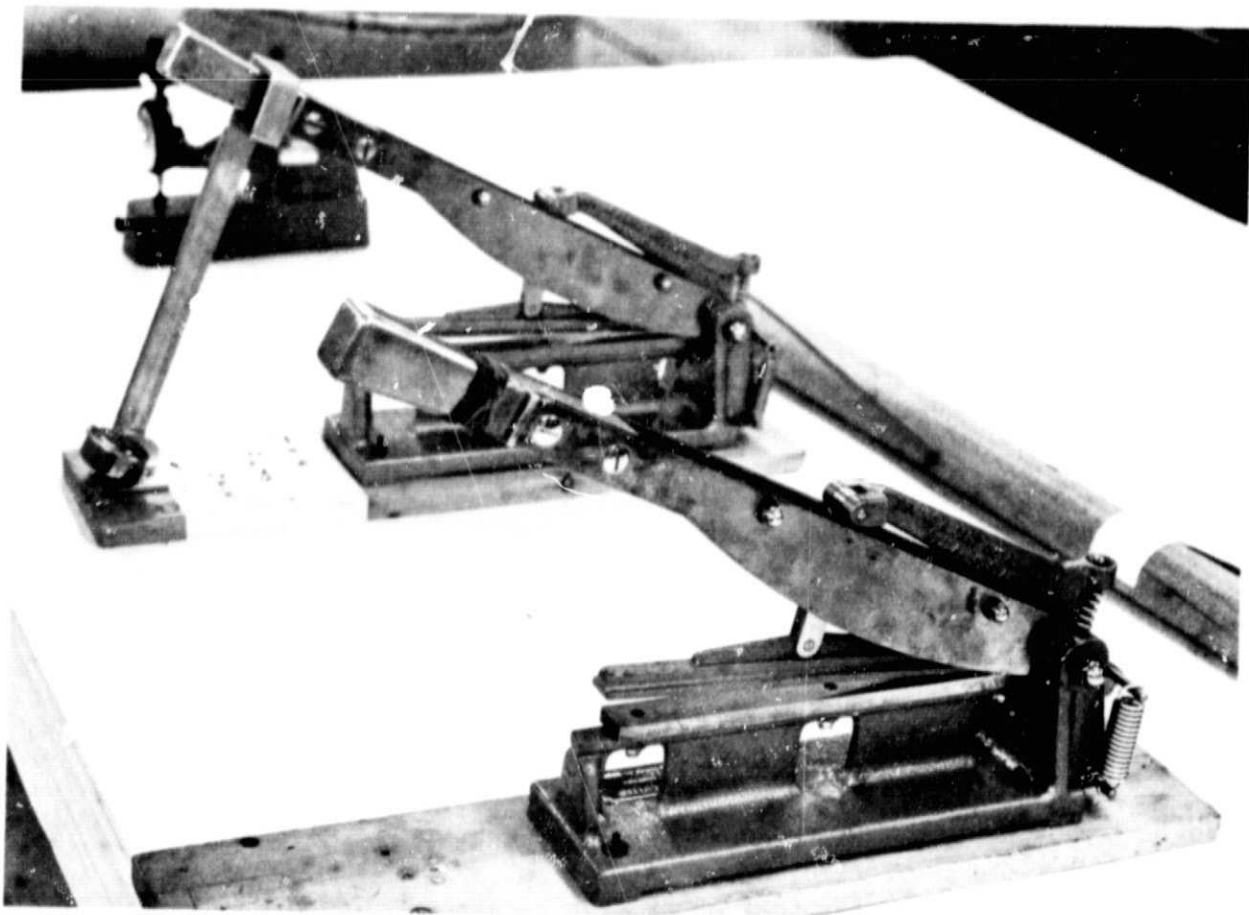
**3.1.2 Biaxial tensile testing.**- Biaxial testing was performed on a fixture which applied loads to a cylindrical test specimen having a diameter of .356 meter (14 inches) and approximate undeformed length of 1.27 meters (50 inches). This device was capable of applying hoop, axial, and torque loads, simultaneously. Hoop loads were produced by internally pressurizing the cylinder specimen; axial loads were imposed by internal pressure and by a pneumatic cylinder which extends the free end of the specimen. Torque loads were applied by another pneumatic cylinder which produced a force tangent to the free end of the specimen.

Stress and strain were recorded for a series of biaxial loads with and without the introduction of shear. Upper limits for each of the materials was established by performing pressure burst tests without the application of torque or axial loads greater than that applied by the internal pressure. Torque application tests were then performed at pressures 50 percent and 75 percent of burst pressure with the circumferential load equal to twice the axial load. These tests were conducted at the same three temperatures as the uniaxial tests discussed above.

Figure 11(a) shows a sleeve specimen installed on the cylinder tester. Figure 11(b) shows the protractor for measuring the shear deformation angle and Figure 11(c) shows the specimen under a shear load. The ease and simplicity of observing the shear deformation is apparent. Figure 11(d) shows the type of failure experienced by the particular test specimen. Longitudinal and circumferential tears initiated at the left end and produced the open triangular flap shown. The white longitudinal band is the Tedlar surface of the seam splice on the inside of the far side of the sleeve. The dark area is the inside fabric

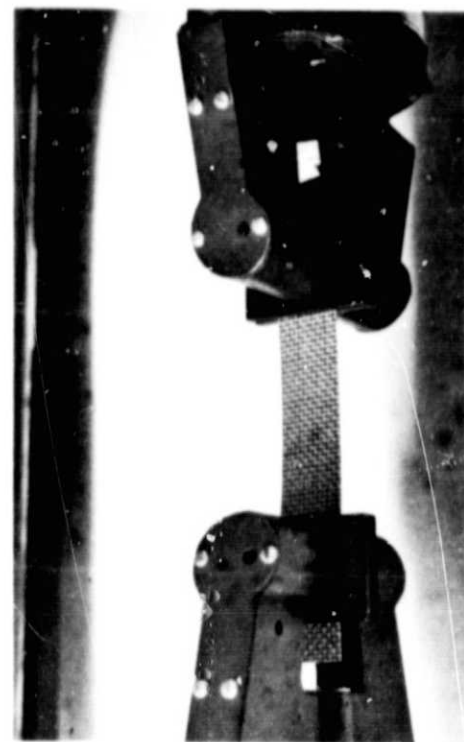
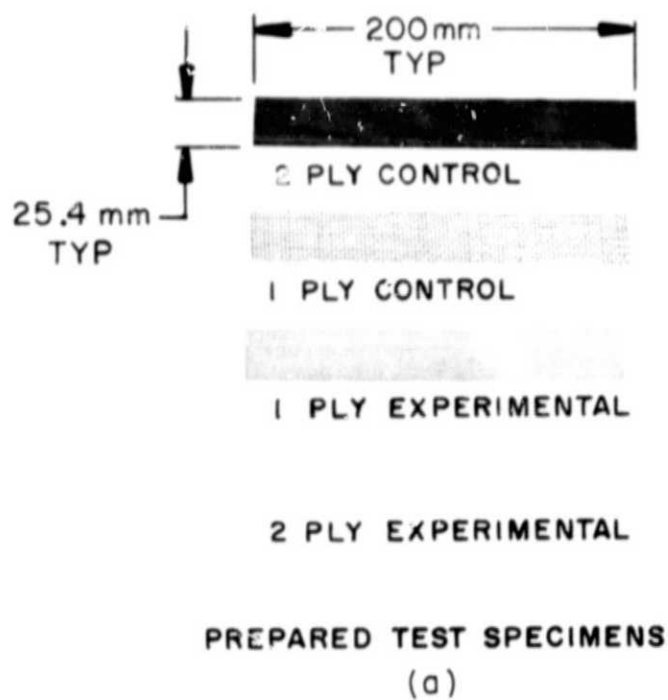


(a)

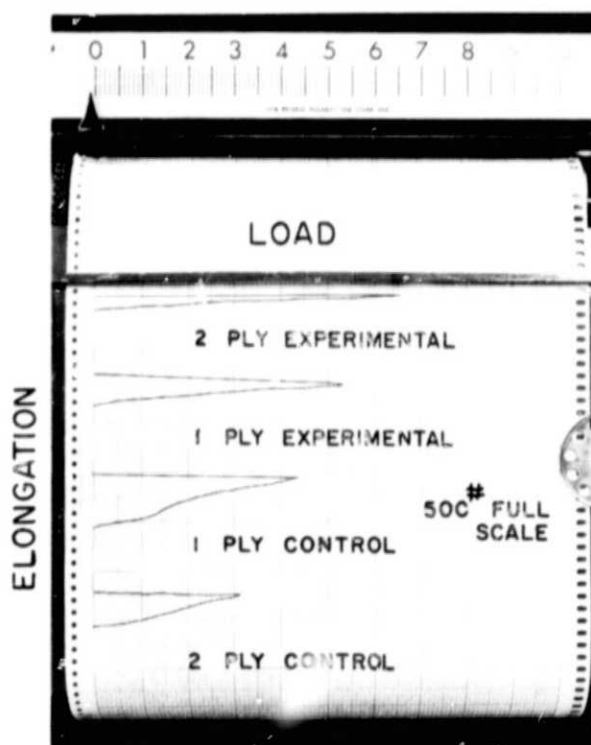


(b) THWING-ALBERT

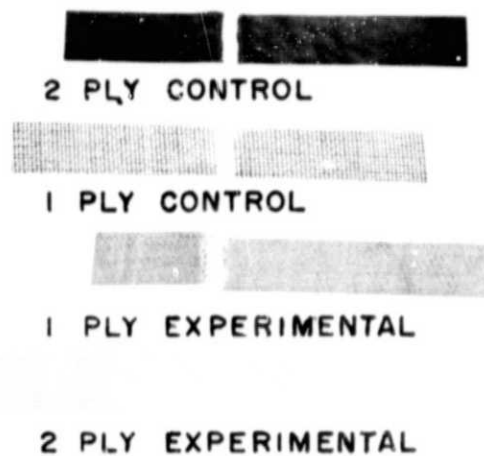
FIGURE 9.- TEST SPECIMEN CUTTERS



TEST MOUNTED SPECIMEN  
(b)

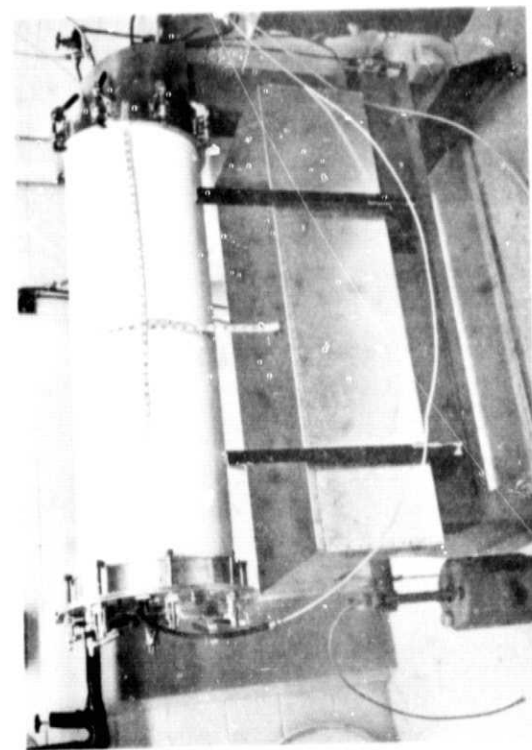


TYPICAL STRESS-STRAIN  
RECORDINGS  
(c)

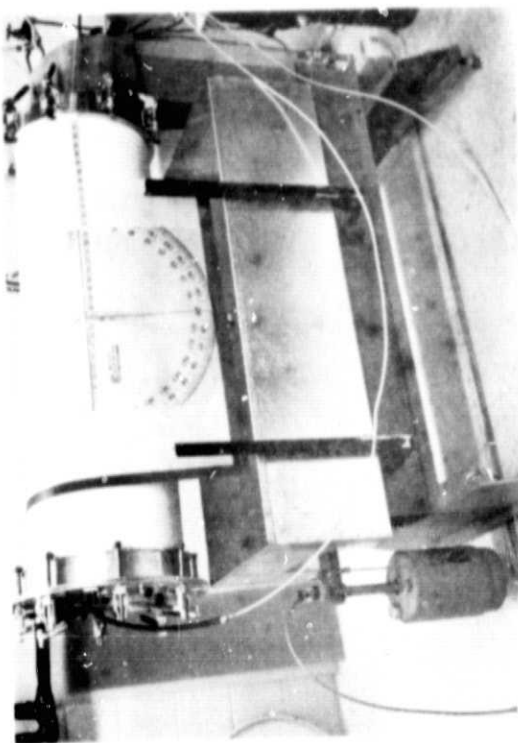


FAILED SPECIMENS  
(d)

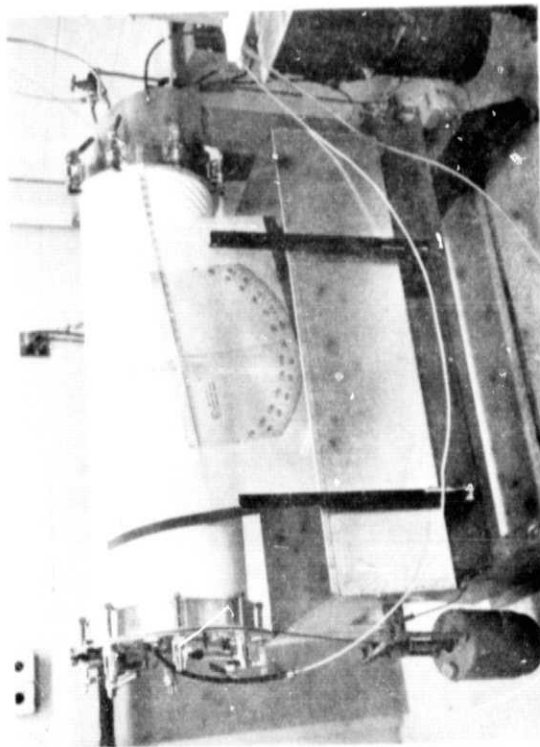
FIGURE 10.- UNIAXIAL TENSILE TESTS



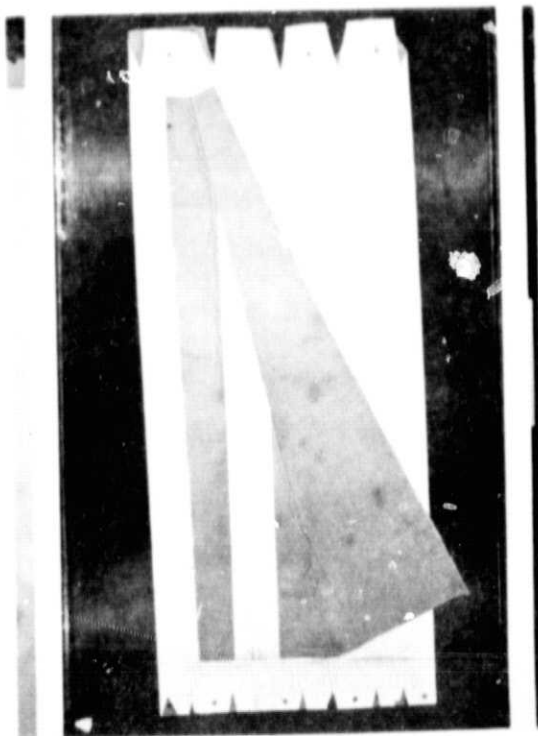
(a) DIAMETER AND LENGTH MEASUREMENT SET-UP



(b) TORSIONAL ANGLE MEASURING DEVICE



(c) TEST WITH TORSIONAL LOAD APPLIED



(d) FAILED SPECIMEN

FIGURE 11.- CYLINDER TEST APPARATUS

layer of the composite material. Generally, material tests results related to seams or end grip effects are not considered valid. For most test materials, it is difficult or impossible to make sleeve specimens without seams. Techniques for winding yarns around a tube of film to produce splice-free sleeves are currently being investigated at Langley Research Center.

Figure 12 illustrates the sequence for clamping the sleeves to the test apparatus. After positioning the sleeve over the mandrel, Figure 12(a), notched, sleeve ends are folded against the end plate, Figure 12(b). A clamp plate, Figure 12(c), secures the sleeve tabs to the end plate.

Fabrication of a sleeve specimen from laminated sheet materials begins with layout from a template, Figure 13(a). Edges to be joined are abutted and secured with thermoplastic tapes by tacking with a small hand sealing iron, Figure 13(b). The load bearing tape applied to the fabric side of the joint, Figure 13(c) and the cover tape applied to the opposite side, Figure 13(d) are permanently bonded in place with a thermal impulse sealing machine.

**3.1.3 Peel strength testing.**- Peel strength measurements on film to fabric bonds were made in accord with ASTM D1876, Reference 3, Figure 14(a). Film to film bonds were tested using Q000066, Method A, Appendix A, illustrated in Figure 14(b). In the former method, both adherends are allowed to flex near the line of failure through angles of approximately 90 degrees. The equilibrium angles of flex vary depending on the relative stiffness of the adherends. In any case, no external control over the angle was exercised. Under Q000066, Method A, one adherend is flexed through 90 degrees or less and the other through a very small angle, Figure 14(b). Due to asymmetry in adherend flexing, all film to film peels were made from the outer surface of the laminate by mounting the fabric side against the drum.

Film-fabric peels under D1876 were run at 0.305 meter (12 inches) per minute and the film to film peels at 0.051 meter (2 inches) per minute. Peel strength is rate sensitive and measurements made at different rates cannot generally be compared.

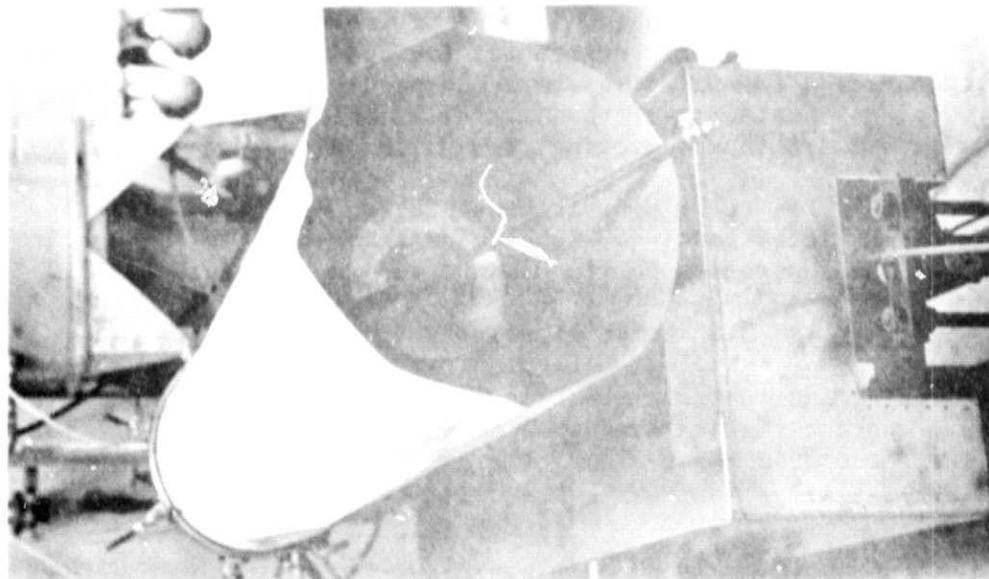
Five samples from the beginning and end of production runs were tested at 22°C (72°F). One end of each specimen was immersed in methylene chloride for 10 to 20 seconds and the plies separated in preparation for testing, Figure 15(b). Values obtained over the initial 12 millimeters (0.5 inch) of peel were disregarded due to the wicking of solvent along the yarns.

The specimen in Figure 15(a) is representative of the appearance of film fabric peel specimens after testing. Some yarns transverse to the specimen axis would pull out of the separating fabric ply and remain bonded to the film side.

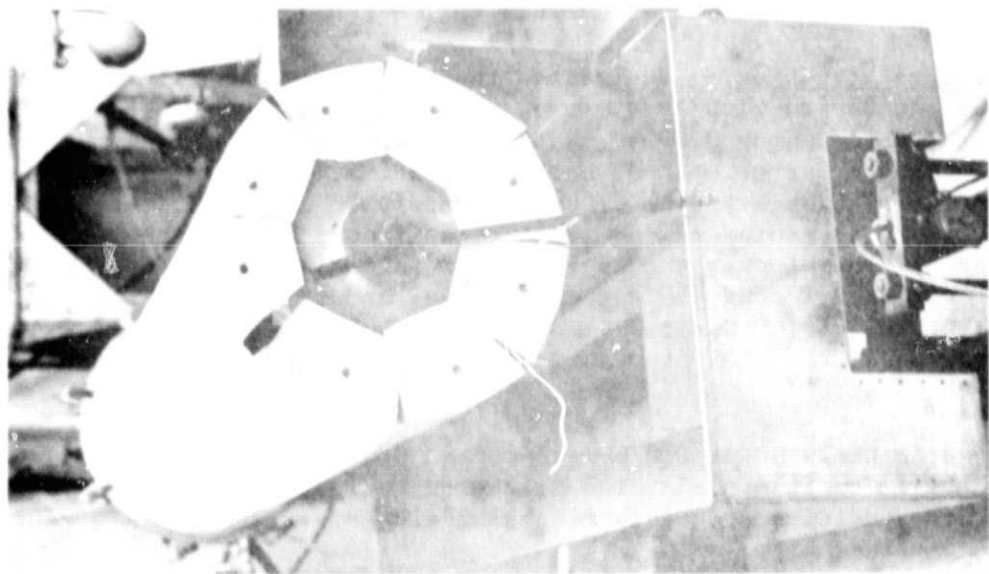
### 3.2 Durability Tests

The experimental and control materials were exposed to wear and durability tests to measure characteristics essential to the performance of inflatable structures. These included measurement of crease, blocking, tear, abrasion and flex effects.

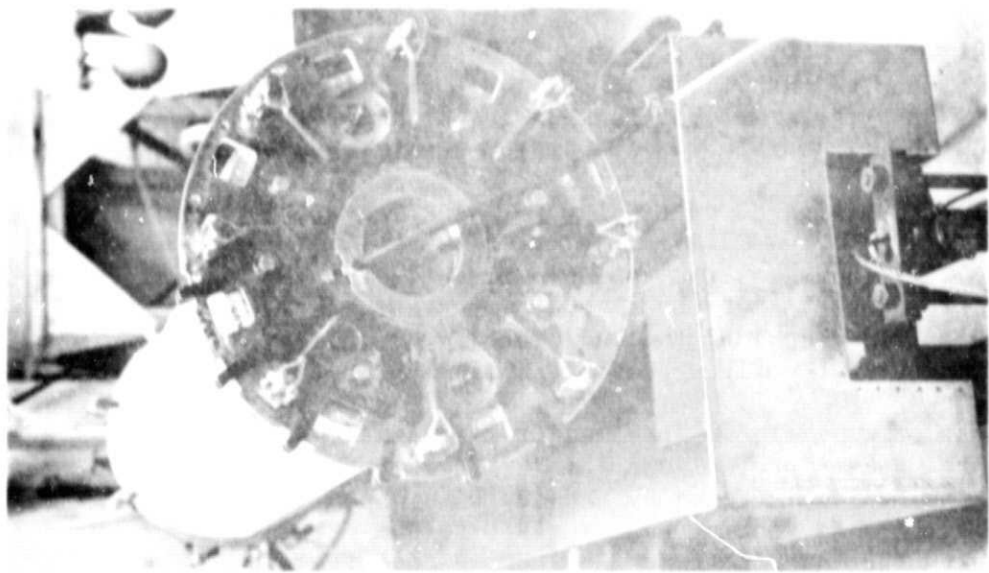




INITIAL MOUNTING  
(a)



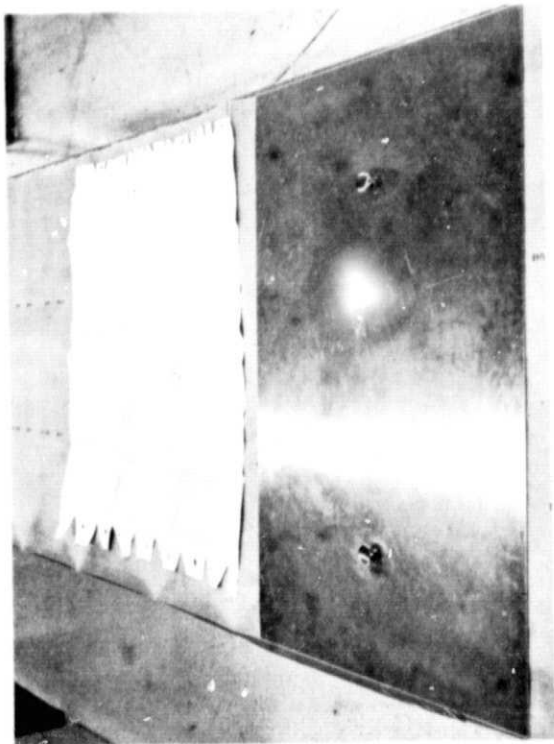
END PREPARATION  
PRIOR TO CLAMPING  
(b)



MOUNTING COMPLETE  
(c)

FIGURE 12.- TEST CYLINDER MOUNTING

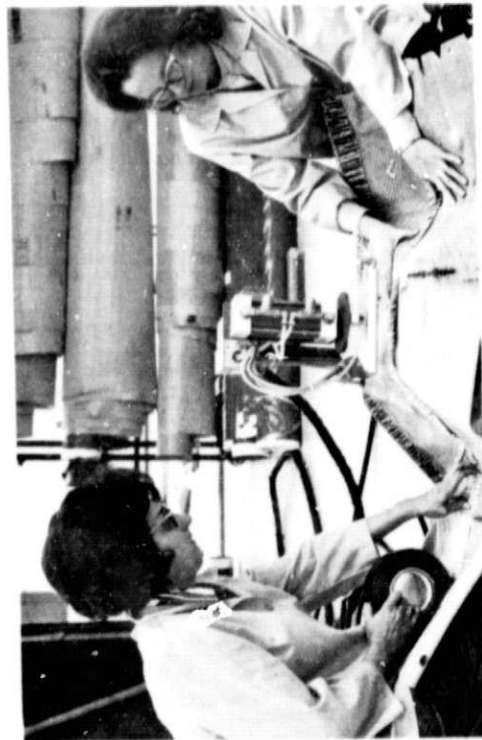




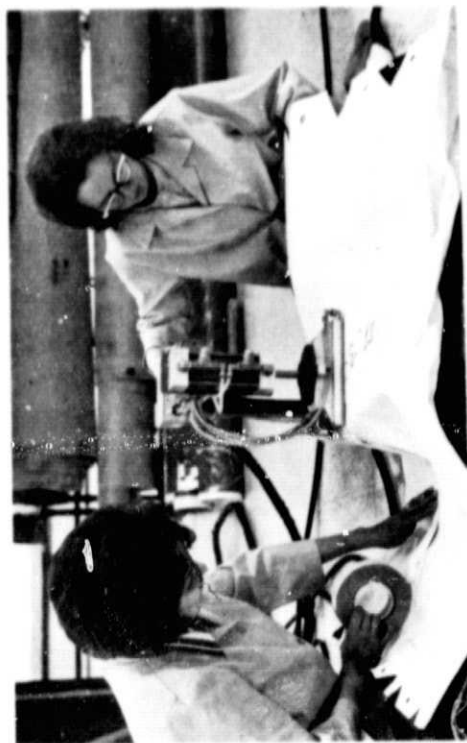
LAYOUT AND CUTTING  
(a)



PRELIMINARY TACK SEAL  
(b)

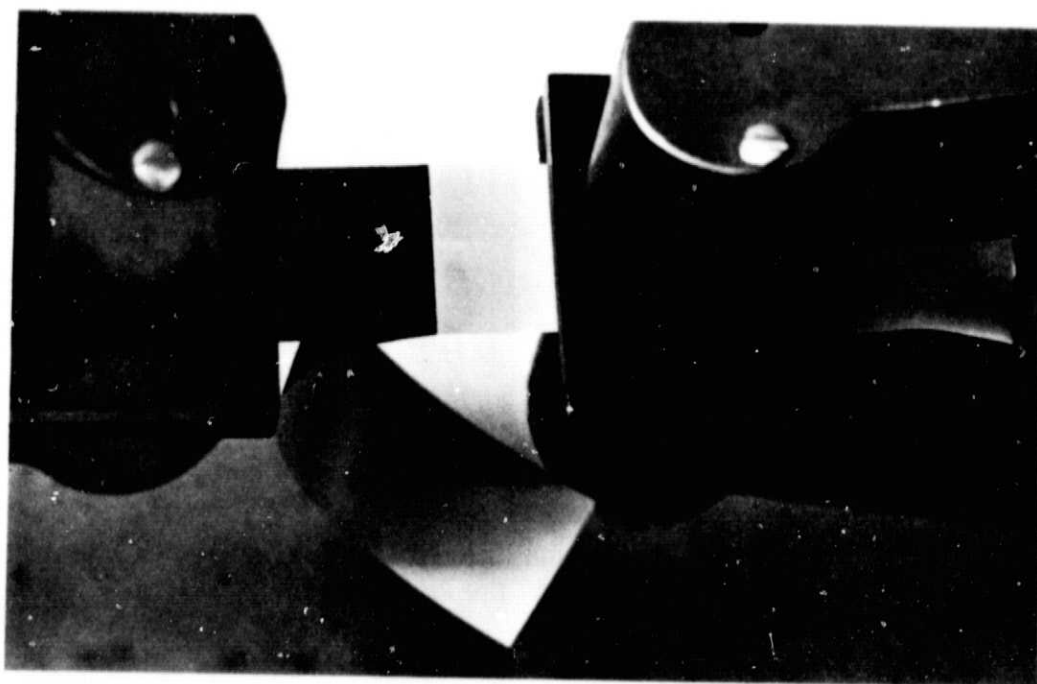


FINAL LOAD TAPE SEAL  
(c)



FINAL COVER TAPE SEAL  
(d)

FIGURE 13.- TEST CYLINDER FABRICATION

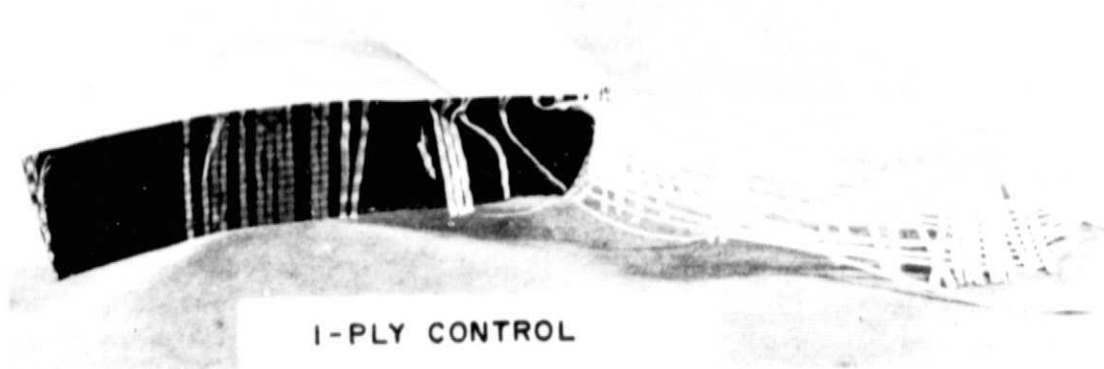


ASTM-D-1876  
(a)



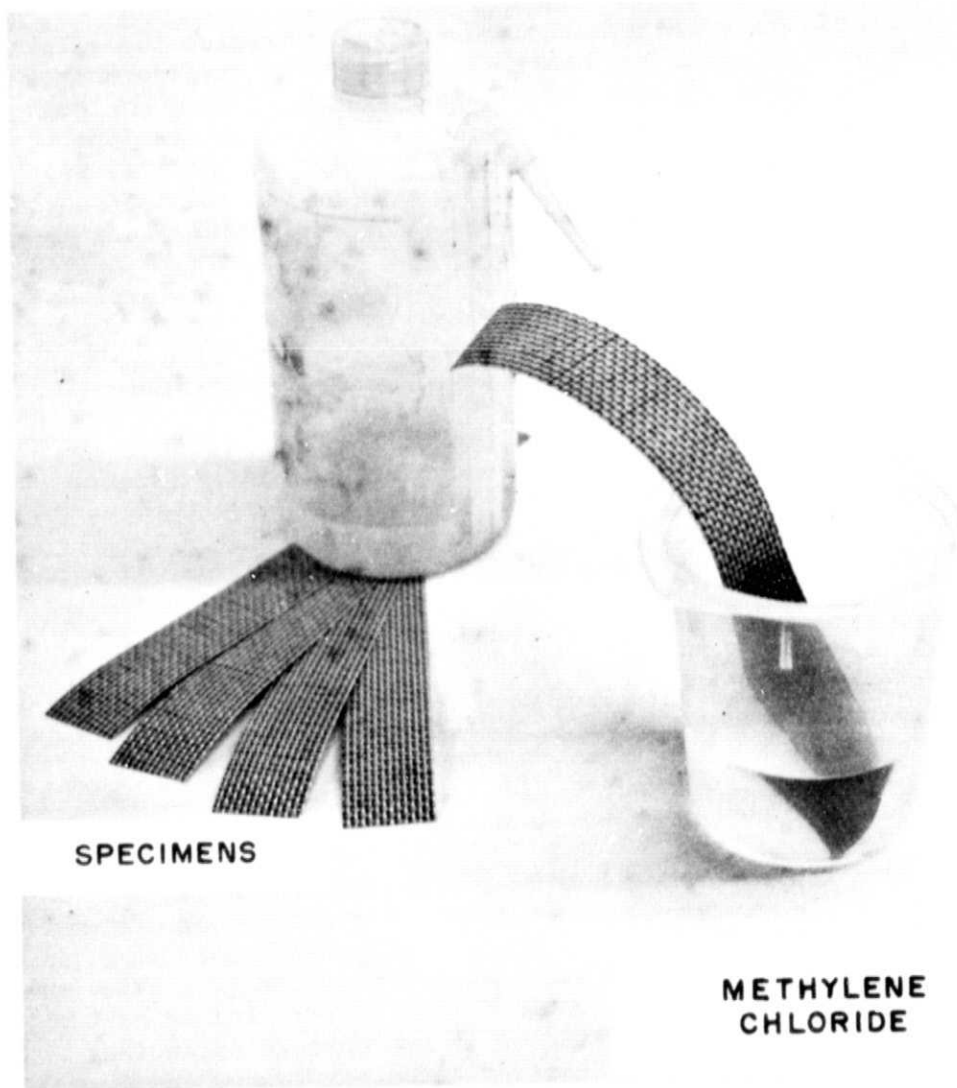
Q-66 METHOD A  
(b)

FIGURE 14. — PEEL TESTING



I-PLY CONTROL

(a) TESTED SPECIMENS



SPECIMENS

METHYLENE  
CHLORIDE

(b) SAMPLE PREPARATION

FIGURE 15.— BOND STRENGTH TESTING

3.2.1 Crease effects.- Coupon samples were cut and accordion folded parallel to the grips with a .0254 meter (1 inch) spacing between folds. The fold was a full 180° sharp crease. The coupons were tested per FTM-5102, Reference 4, like the uniaxial tensile tests to determine the loss in strength. Five (5) samples were tested for each material at 22°C (72°F).

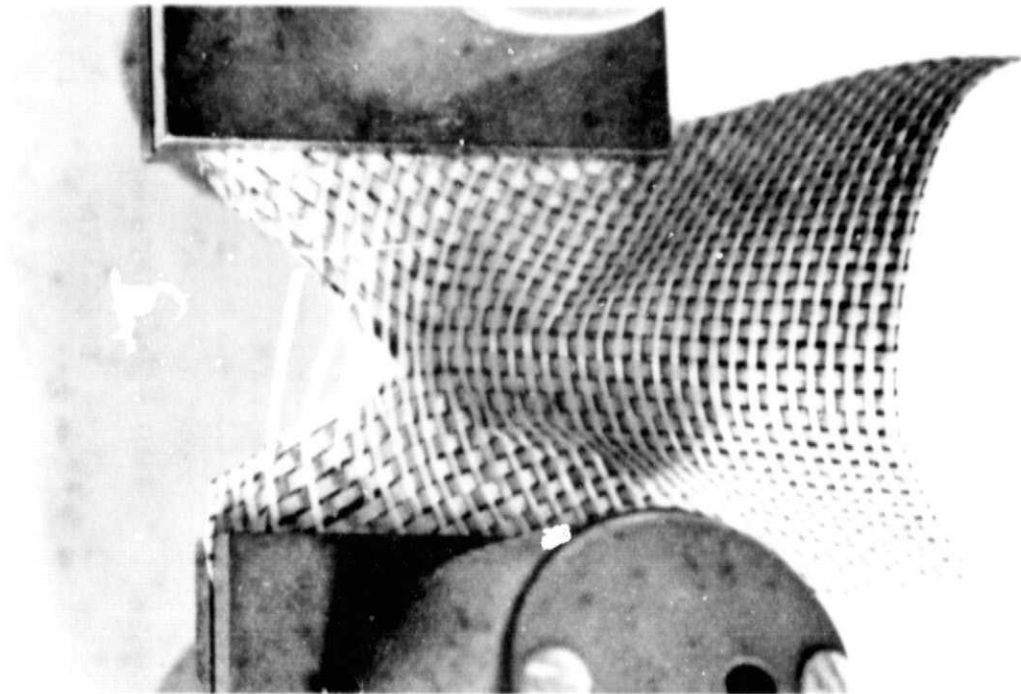
3.2.2. Blocking test.- The test method is described in Specification Q000041, Appendix B. With this method a dead load of 89 newtons (20 pounds) was applied to a sample of .051 meter x .203 meter (2 inches x 8 inches) folded into a .051 meter x .051 meter (2 inches x 2 inches) square. The load is applied for 24 hours at 71°C (160°F), and the force required to separate the layers is determined. Five (5) sample specimens were investigated for each of the two (2) laminate materials since the coating materials used in the 2-ply materials do not exhibit measureable blocking effects.

3.2.3 Abrasion test.- Abrasion tests were conducted to determine the effect of wear produced when an inflatable structure is packaged and transported in the deflated state. The method employed uses a dead weight of 44.5 newtons (10 pounds) acting on a .002 square meter (3.14 square inch) circular pad which reciprocates against a horizontal plate at 60 strokes per minute, Fig. 16. For each test, one piece of the test fabric was secured to the pad and another about 30 centimeters (1 foot) square was secured to the horizontal plate so that two identical surfaces were rubbed together. Laminate materials were tested Tedlar to Tedlar and coated materials Hypalon to Hypalon. Wear failure was assumed to have occurred when specimens were worn down to the fabric. One sample of each material was tested at ambient conditions. Typical sample appearance after failure and test record forms are illustrated in Figure 16.

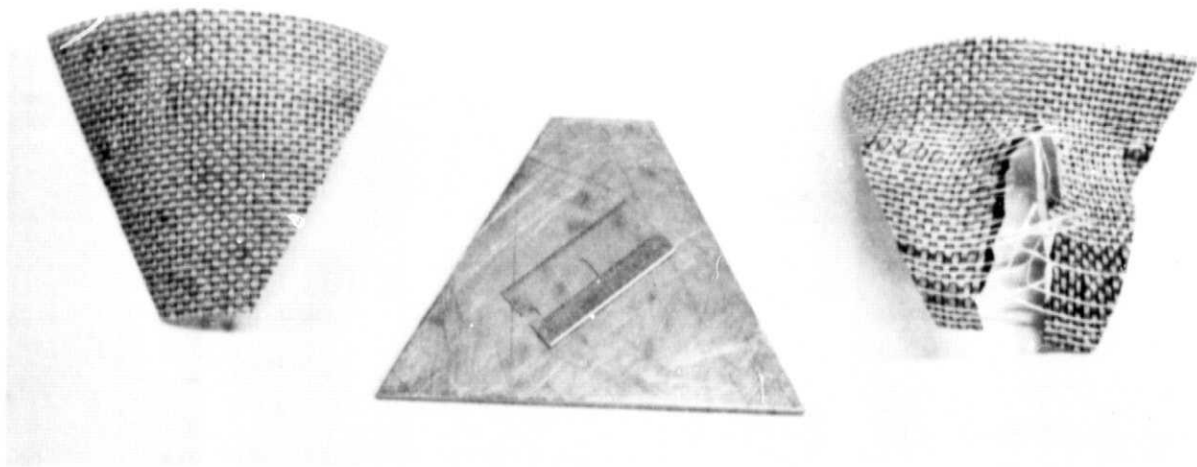
3.2.4 Trapezoidal tear tests.- Federal Test Method 5136, Reference 4, was employed in these tests. Sample size form is a right trapezoid .076 meter (3 inches) high with bases of 0.0025 M (1 inch) and 0.102 M (4 inches) as shown in Figure 17(b). The test specimen is notched on the .025 M (1 inch) base and clamped with the two non-parallel edges gripped in the jaws as shown in Figure 17 (a). Grip separation rate was .305 meter (12 inches) per minute. Five specimens of each material were tested at a temperature of 22°C (72°F). A standard trapezoidal template is shown in Figure 17(b) along with a cut sample and a tested and torn sample. The tear is normal to the warp yarns and generally a minimum tear force is noted along orthogonal tears. Bias tears require much higher tear forces. Loose uncoated weaves show greater tear strength than impregnated and coated and/or close weave materials. These features allow the fabricator to design for improved tear characteristics.

3.2.5 Flex tests.- Flex tests were conducted on a Bally Flexometer, Figure 18(a). Rectangular fabric specimens 70 by 45 millimeters were folded in half parallel to the shorter dimension, then folded in half again at right angles, Figure 18(b) and (d). Warp yarns were aligned with the 70 millimeter dimension. Diagonally opposite from the double folded corner, the inner two free corners are secured to one clamp and the outer two corners to another clamp. During the test, one clamp reciprocates alternately toward and away from the other, causing the specimen to be flexed in the vicinity of the double fold at 100 cycles per minute. One specimen of each material type was tested to determine the number of cycles to failure in simulation of the effect of turbulent air flow over a balloon envelope.



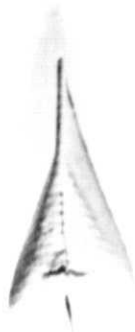


(a) SPECIMEN UNDER TEST

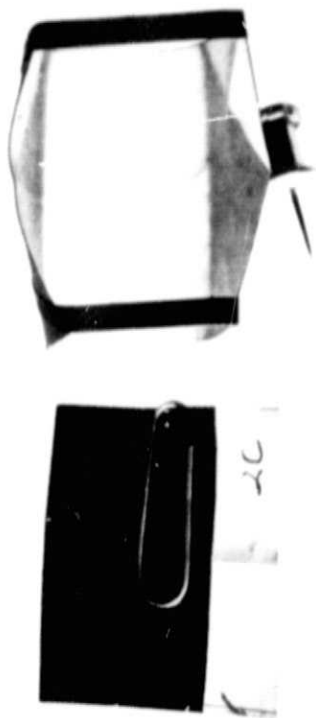


(b) TEST SPECIMENS - BEFORE AND AFTER TESTING

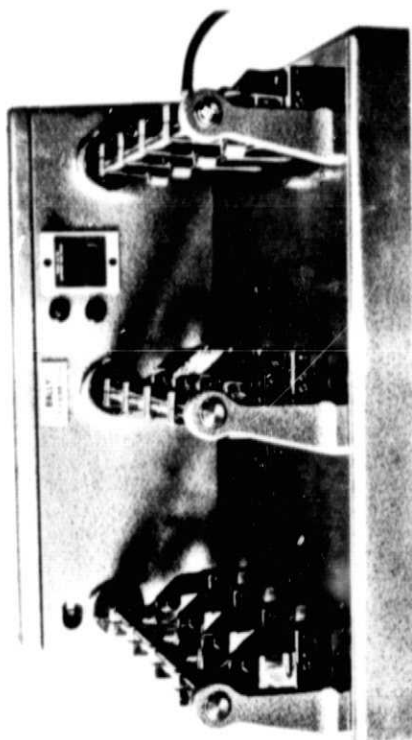
FIGURE 17.— TRAPEZOIDAL TEAR TESTING



(b) SINGLE PLY CONTROL SPECIMENS



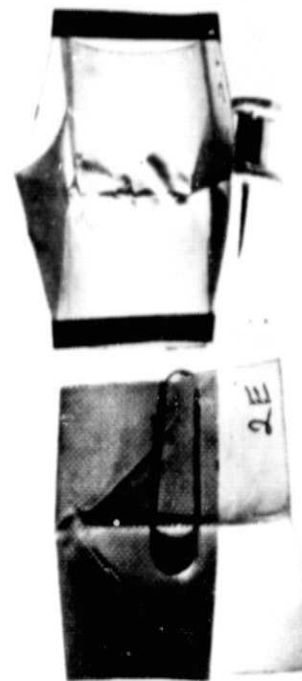
(c) TWO PLY CONTROL SPECIMENS



(d) BALLY FLEXOMETER



(d) SINGLE PLY EXPERIMENTAL



(e) TWO PLY EXPERIMENTAL SPECIMENS

FIGURE 18.- FLEX TESTING



### 3.3 Geometric Properties

Composite weight and permeability depend on the geometry and constituency of the lamina.

**3.3.1 Weight measurements.-** Weight measurements were made by cutting a 0.152 m. x 0.152 m. (6 inch x 6 inch) sample of each material and weighing it on a laboratory balance. For the conventional laminate material another weight parameter was measured. Since the fabric is a relatively loose weave a weave set compound is added to afford dimensional stability. A sample of the material was cut and weighed as above, then boiled in 2 liters of water for an hour and weighed again after drying to determine the amount of weave set (see Figure 19).

**3.3.3 Helium permeability tests.-** Federal Test Method 5460 was used for the helium permeability tests. The unit of measure is liters of helium permeated per square meter of material in 24 hours. Sample size was a .140 meter (5½ inch) diameter circle of material. Three (3) sample specimens of each material were tested at 22°C (72°F). All permeability tests were performed on virgin, uncreased and unstressed material samples.

The edges of the circular specimen shown in the foreground of Figure 20 were coated with a soft wax and clamped between the hinged circular plates shown at the left. Helium introduced through the lower plate diffuses through the specimen and its concentration between the specimen and upper plate is sensed by an analysis cell connected to the galvanometer through a Wheatstone bridge. Two readings taken at fixed time intervals establish the permeation rate per unit area.

## 4.0 TEST RESULTS AND DISCUSSION

Strength test data have been obtained by uniaxial and biaxial testing and by peel tests. Durability test data are available from crease, abrasion, blocking, tear and flex tests. Geometric test data are furnished on helium permeability and constituent weights.

### 4.1 Strength Test Results

As noted in Section 3.1.1, coupon testing of composites may yield questionable data due to the inability to fully involve yarns inclined at angles to the test direction. Considerable differences in test results were found for fabric based materials when tested biaxially and when tested uniaxially.

**4.1.1 Uniaxial tensile data.-** Averages of uniaxial test data for tensile strength and elongation in both machine and transverse directions are shown for the four materials and the three test temperatures in Table 2 and Figure 21.

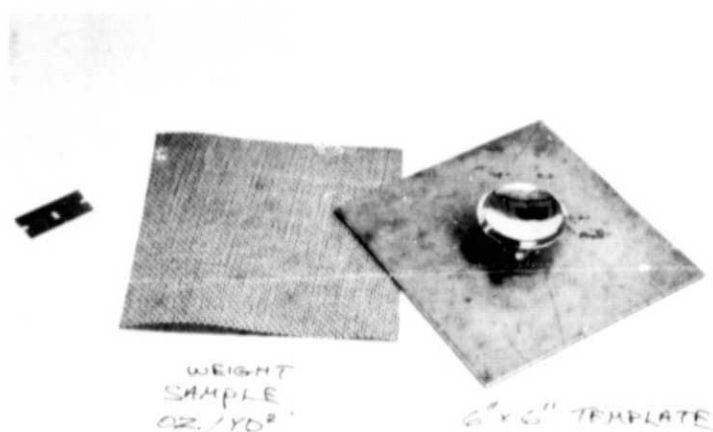
As expected, the data show that tensile values increase as temperature decreases and elongations vary inversely with the tensile strength. The clamping technique used for the laminate materials had to be changed at the -51°C (-60°F) condition since excessive slippage in the jaws produced unequal filament loading and premature specimen failure. Fiber slippage was reduced to a minimum by snubbing the specimen ends in a pair of "D" shaped rings in place of the clamp-type grips. This effect was not observed with the coated materials apparently because the yarns are held more firmly in the coating and little slippage occurs in the jaws.





WEAVE SET (SIZING) TEST APPARATUS

(a)



SAMPLE TEMPLATE & PREPARATION

(b)



LABORATORY BALANCE

(c)

FIGURE 19.- WEIGHT MEASUREMENT

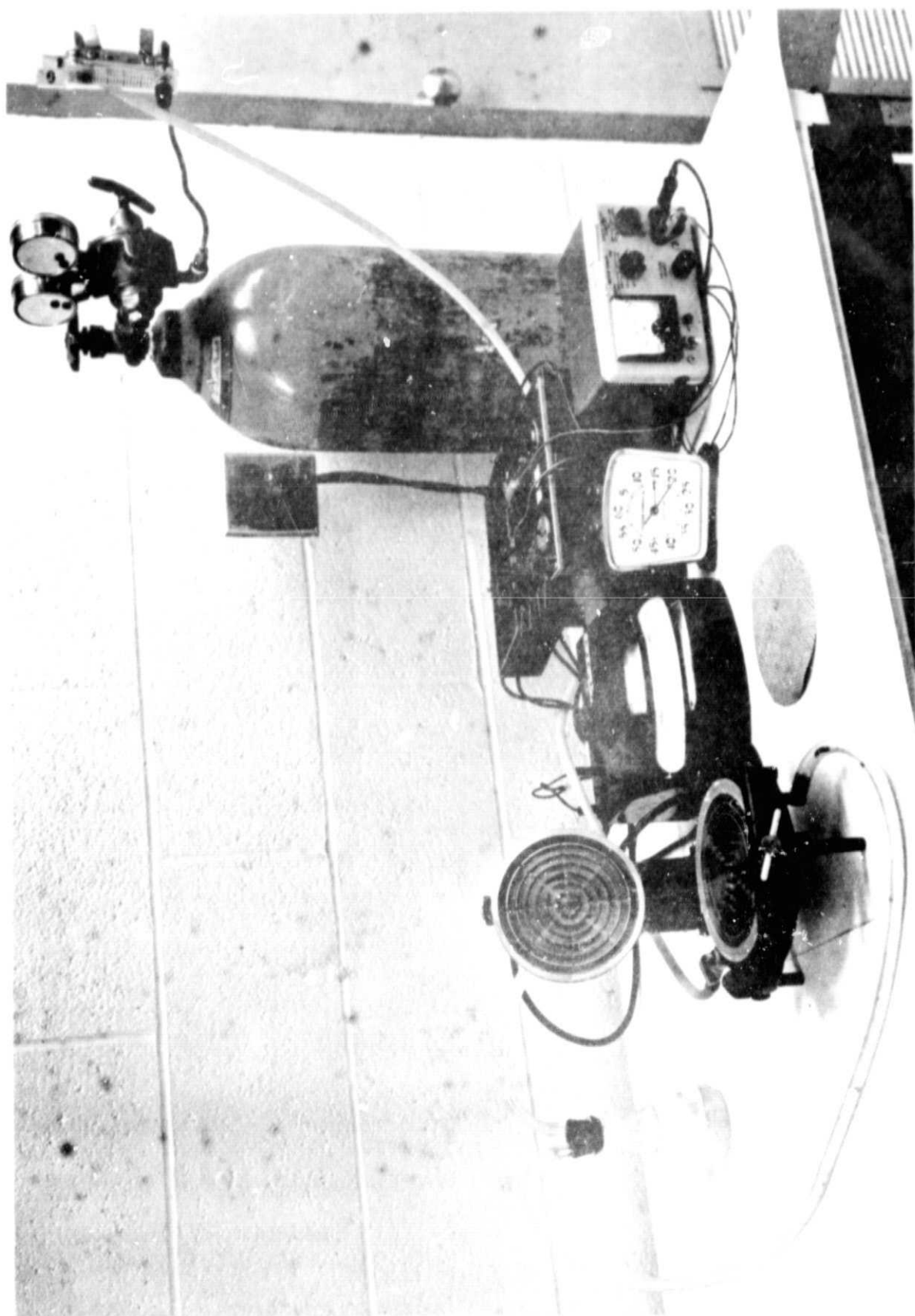


FIGURE 20.— PERMEABILITY TEST APPARATUS

TABLE 2

## UNIAXIAL TEST DATA SUMMARY

Average Tensile Values, Newtons/meter (pounds per inch)

TEST TEMPERATURE °C	1 Ply Control		2 Ply Control		1 Ply Exp.		2 Ply Exp.	
	MD	TD	MD	TD	MD	TD	MD	TD
60°C (140°F)	40,250 (230)	38,500 (220)	30,275 (173)	25,900 (148)	44,975 (257)	52,500 (300)	57,925 (331)	53,025 (303)
22°C (72°F)	45,850 (262)	46,025 (263)	32,200 (184)	26,950 (154)	47,075 (269)	57,750 (330)	68,950 (394)	73,500 (420)
-51°C (-60°F)	45,150 (258)	45,675 (261)	37,800 (216)	36,750 (210)	56,175 (321)	58,450 (334)	80,500 (460)	79,975 (457)

Average Percent Elongation at Break								
60°C (140°F)	25.0	40.0	29.0	32.0	14.0	6.0	10.0	9.0
22°C (72°F)	24.0	40.0	27.0	29.0	13.0	6.0	9.0	7.0
-51°C (-60°F)	12.0	29.0	18.0	23.0	5.0	6.0	8.0	6.0

MD = Machine Direction  
TD = Transverse Direction

Machine Direction  
Transverse Direction

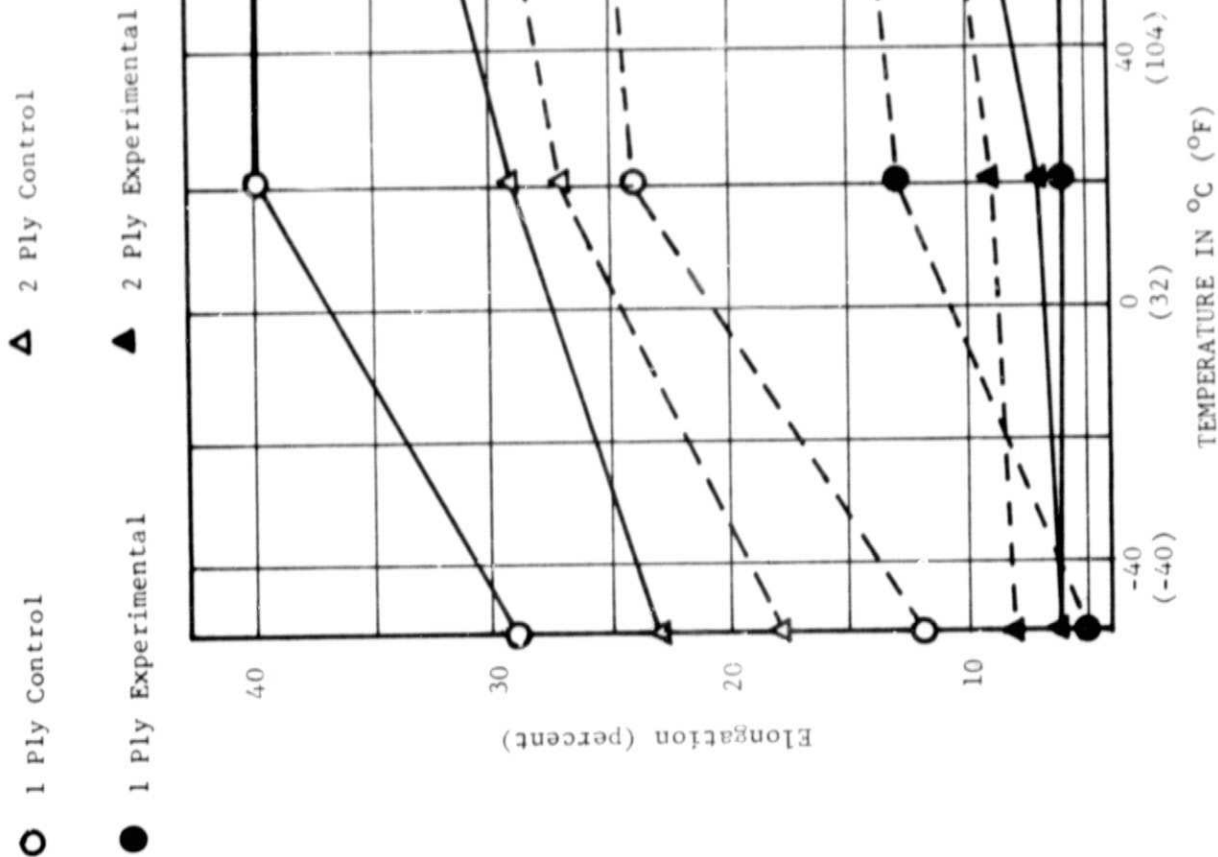
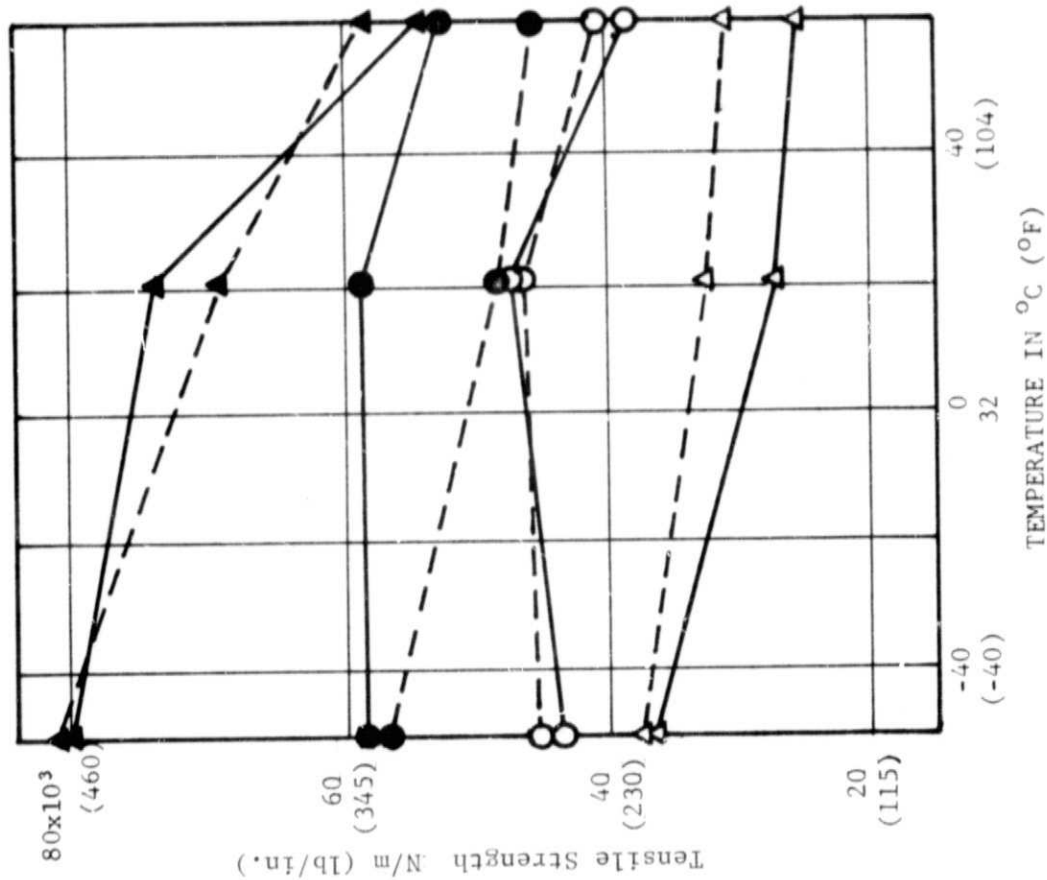


FIGURE 21

VARIATION OF ULTIMATE UNIAXIAL TENSILE STRENGTH AND ELONGATION WITH TEMPERATURE

4.1.2 Biaxial tensile results.— Biaxial test data on the ultimate strength of the materials was limited by extensive difficulties with the test apparatus.

In previous cylinder testing, Reference 1, hoop loads were applied pneumatically. Since some of the Kevlar based materials being tested had more than twice the strength of previous materials tested, sudden rupture of a Kevlar sleeve presents a considerable ballistic and acoustic hazard to personnel.

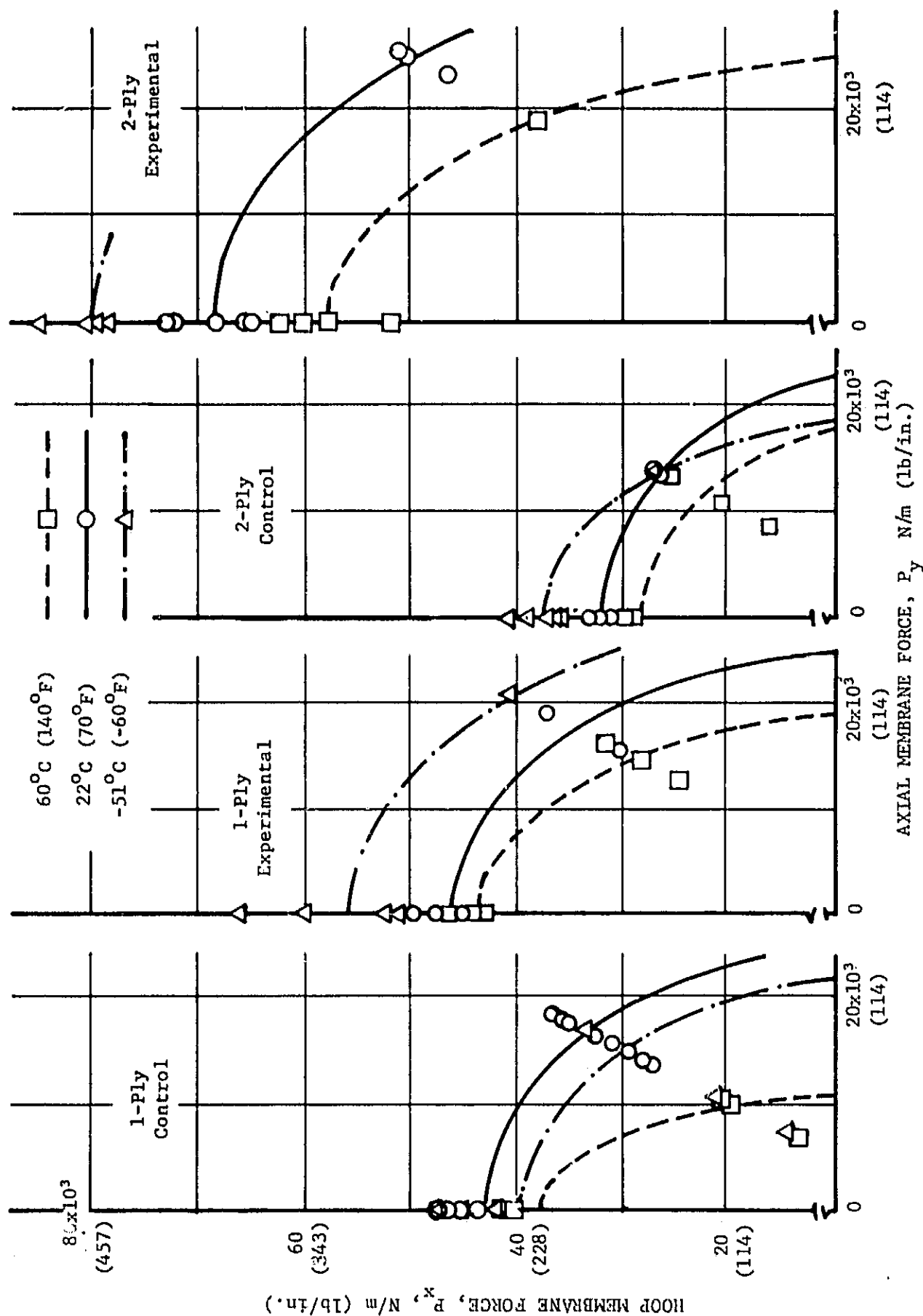
To obviate these hazards, sleeves tested in this investigation were loaded hydraulically by filling them with a fluid of water and alcohol. The principle difficulties with this method were:

- (a) Distortion of the material specimen from a true, axi-symmetric form due to the fluid weight.
- (b) Delamination of the materials due to fluid leaking into imperfections in the material surface.
- (c) The extensive test cycle time produced by the modest size of equipment used to heat, cool, and pump the fluid, particularly at  $-51^{\circ}\text{C}$  ( $-60^{\circ}\text{F}$ ) where the liquid became a slurry.
- (d) Control of the fluid after rupture.

In addition, the original clamping system used to secure the sleeves to the end plate proved to be marginal at the high axial loads of 90,000 N (20,000 lb) required to fail the heavier sleeve specimens. After considerable development, end grips were obtained that would carry specimens to failure. The final configuration, only partially successful, consisted of a wedge-section ring and mating insert bolted together to clamp the sleeve end. A seal was provided by a pressurized torus between the sleeve and the end plates. The clamping of high strength composite materials appears to be a nearly universal problem among experimenters.

Loads were applied by first pressurizing the interior of the cylinder specimen, superimposing an axial load and then introducing shear stress by turning the free end of the specimen until failure occurred. A biaxial stress ratio  $P_x/P_y=2$  was chosen for the measurements reported here as representative of the conditions in a cylindrical structure like an aerodynamically shaped, tethered balloon. Because of the area occupied by the axial cylinder rod, a small axial force adjustment was required in addition to specimen pressurization to obtain a stress ratio of 2. Most failed specimens exhibited tears along the axial direction extending about half the specimen length.

Figure 22 shows the effect of temperature on ultimate hoop and axial stress. Machine direction, uniaxial ( $P_x/P_y=0$ ) failure stress data (Table 2) were plotted along the ordinates and ellipses fitted by standard, least squares techniques. Biaxial strength of the experimental (Kevlar fabric) materials varied inversely with the temperature as might reasonably be expected from the temperature-strength variations of the constituents. For the conventional, Dacron-based materials, the results suggest some strength loss at low temperatures.



FAILURE STRESS AT ZERO SHEAR STRESS,  $P_{xy} = 0$

FIGURE 22

Curves developed similarly for biaxial stress accompanied by shear, Figure 23, exhibit similar temperature effects. It was found necessary to apply at least 40 per cent of the biaxial failure load measured at  $P_{XY}=0$  to prevent instability and specimen buckling before shear failure occurred.

Figures 22 and 23 indicate that the relative strength levels of the materials tested at various temperatures under combined loading could be inferred from the uniaxial failure data. Where knowledge of absolute strength is required, however, as in design of inflatable structures, biaxial-shear test data approximating the anticipated service loads should be obtained.

**4.1.3 Elastic Characteristics.**—Stress-strain data acquired during the biaxial tensile tests were used to determine the biaxial elastic and shear stiffness coefficients. Stress-strain data for the hoop direction (material machine direction) at  $P_X/P_Y=2$ ,  $P_{XY}=0$  and various temperatures is shown in Figure 24. Each line represents one cylinder test specimen. Elastic coefficients for each material and temperature, Figure 25, were determined at 50 and at 75 per cent of burst stress by measuring the slope of tangents to the curves in Figure 24.

The shear stress-strain relations obtained at 50 and 75 per cent of the biaxial burst load were quite linear from zero shear up to shear failure. The slope of these relations were taken as a measure of the shear stiffness, Figure 26.

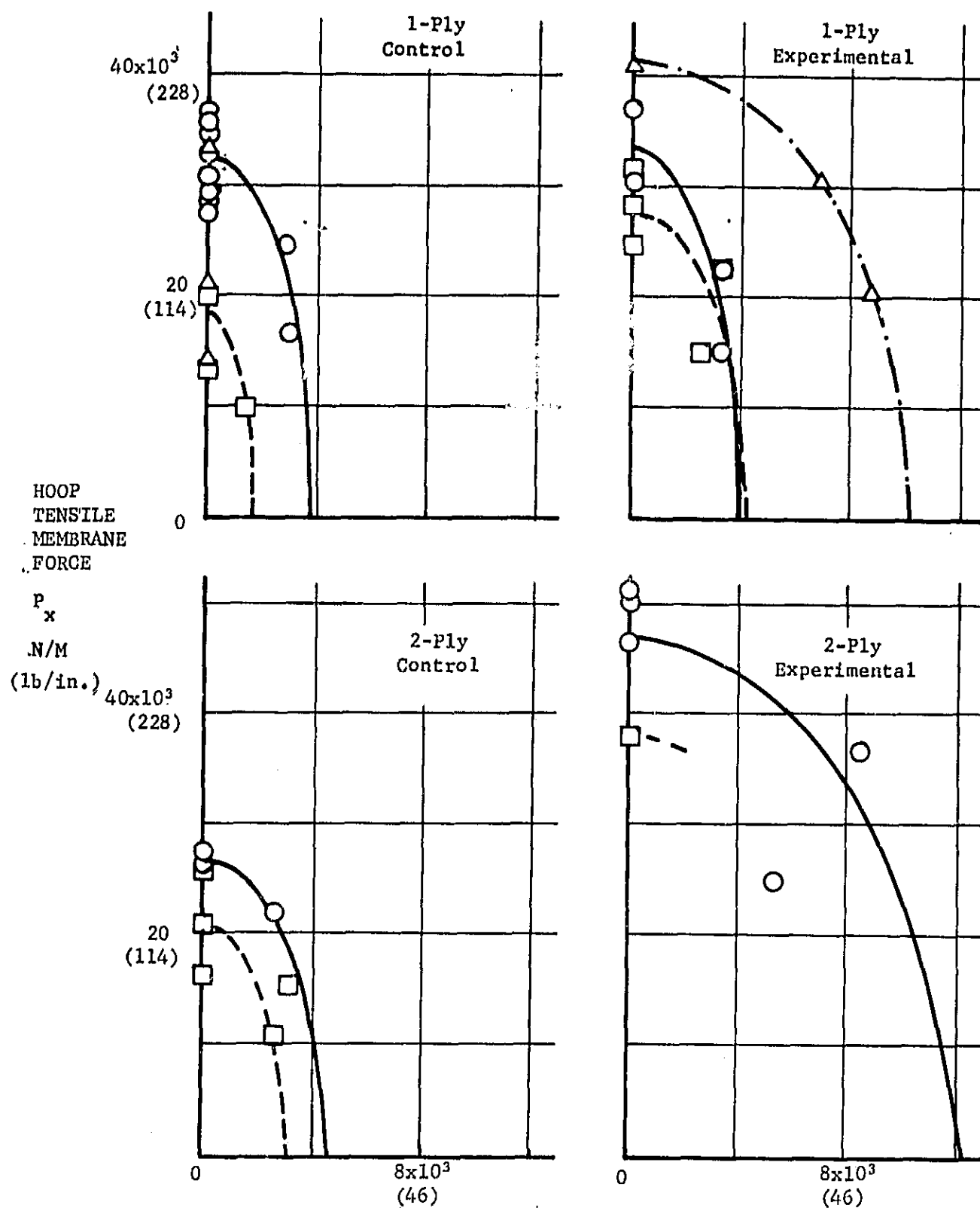
The Kevlar composites display increased dimensional rigidity relative to the control materials as would be expected from use of the high modulus fibers. For example, the single ply Kevlar laminate, Figure 25, shows about three times the stiffness ( $E_t$ ) in the machine direction as the single ply Dacron control material. The two-ply Kevlar material has about ten times the stiffness of the corresponding Dacron, two-ply. The high rigidity of the Kevlar composites is an advantageous characteristic for many structural applications, but is a disadvantage in applications requiring folding and high density packaging.

Most of the materials tested showed high variability of shear stiffness with temperature, Figure 26. Although the film components in the single ply fabric laminates probably determine the shear load at failure (Figure 23), the significant contribution of the fabric to shear stiffness is indicated by the more than two-fold increase in shear stiffness produced by replacing Dacron with Kevlar in the experimental laminate. The data indicate that shear stiffness rises with an increase in the biaxial stress field. For example, the 22°C (72°F) shear stiffness of the single ply control and two ply experimental materials increased more than fifty per cent when the biaxial stress level was increased from 50 to 75 per cent of ultimate.

Adequate characterization of the elastic behavior of these materials will require further testing.

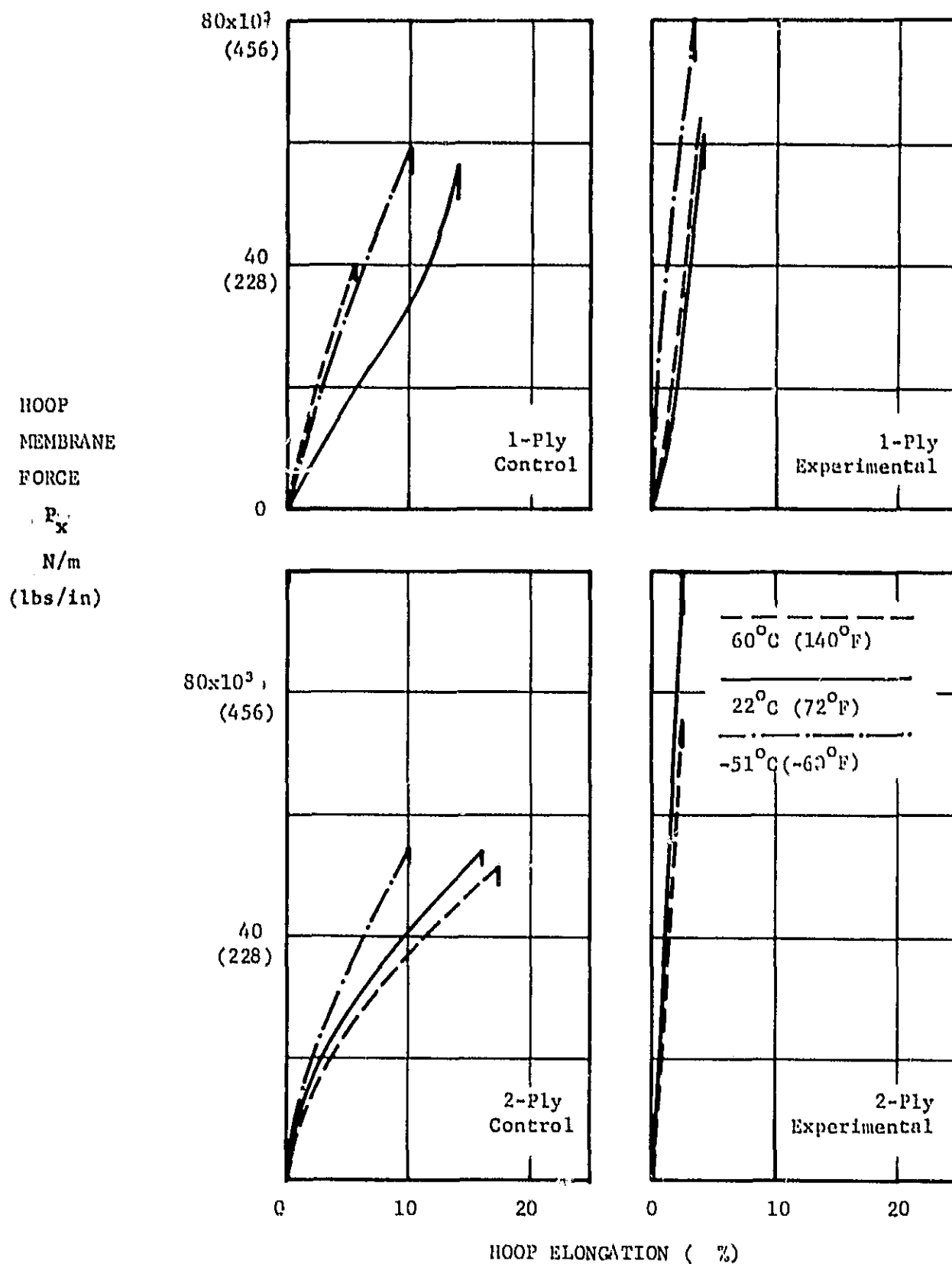
**4.1.4 Peel strength data.**—The film to film (A and B, Table 3) peel strengths of control and experimental materials were fairly consistent. The addition of the adhesive wash coat reduced the peel strength of the film-fabric interface (C-Table 3) in about the same proportion as water immersion. The "dry" peel strength of this interface for the Kevlar experimental laminates was about two-thirds of the Dacron laminate. The wider yarn spacing in the Dacron fabric

-50°C (-60°F)    - - - Δ - - -    22°C (72°F)    — ○ —    60°C (140°F)    - - - □ - - -



FAILURE STRESS AT BIAXIAL LOAD COMBINATION OF  $P_x/P_y = 2$





STRESS-STRAIN RELATIONS AT BIAXIAL  
STRESS COMBINATION  $P_x/P_y = 2$  AND ZERO SHEAR LOAD

FIGURE 24

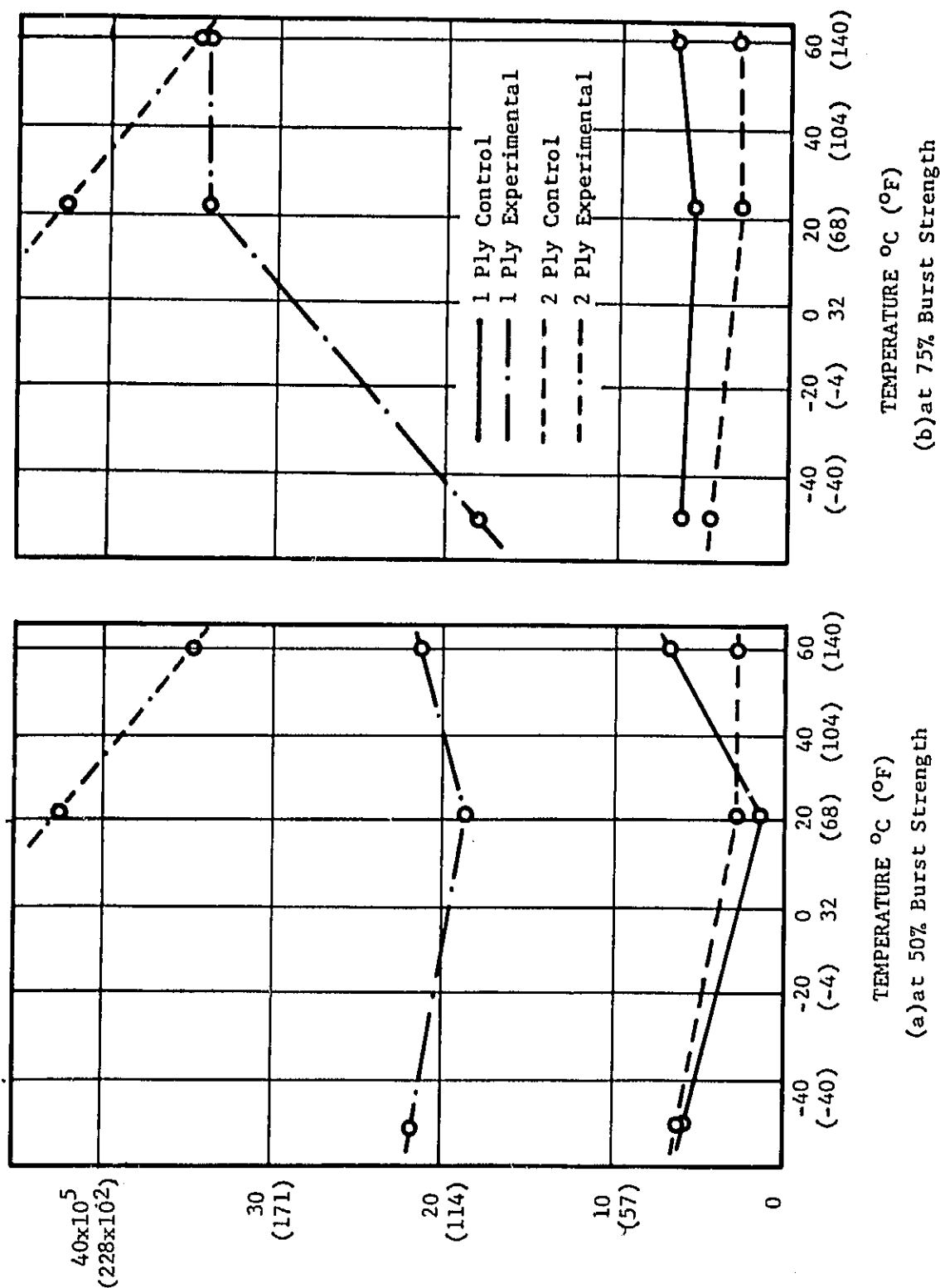


FIGURE 25: EFFECT OF TEMPERATURE ON CIRCUMFERENTIAL (MACHINE DIRECTION)  
ELASTIC COEFFICIENT FOR BIAxIAL LOAD COMBINATION OF  $P_X/P_Y=2$ ;  $P_{XY}=0$ .

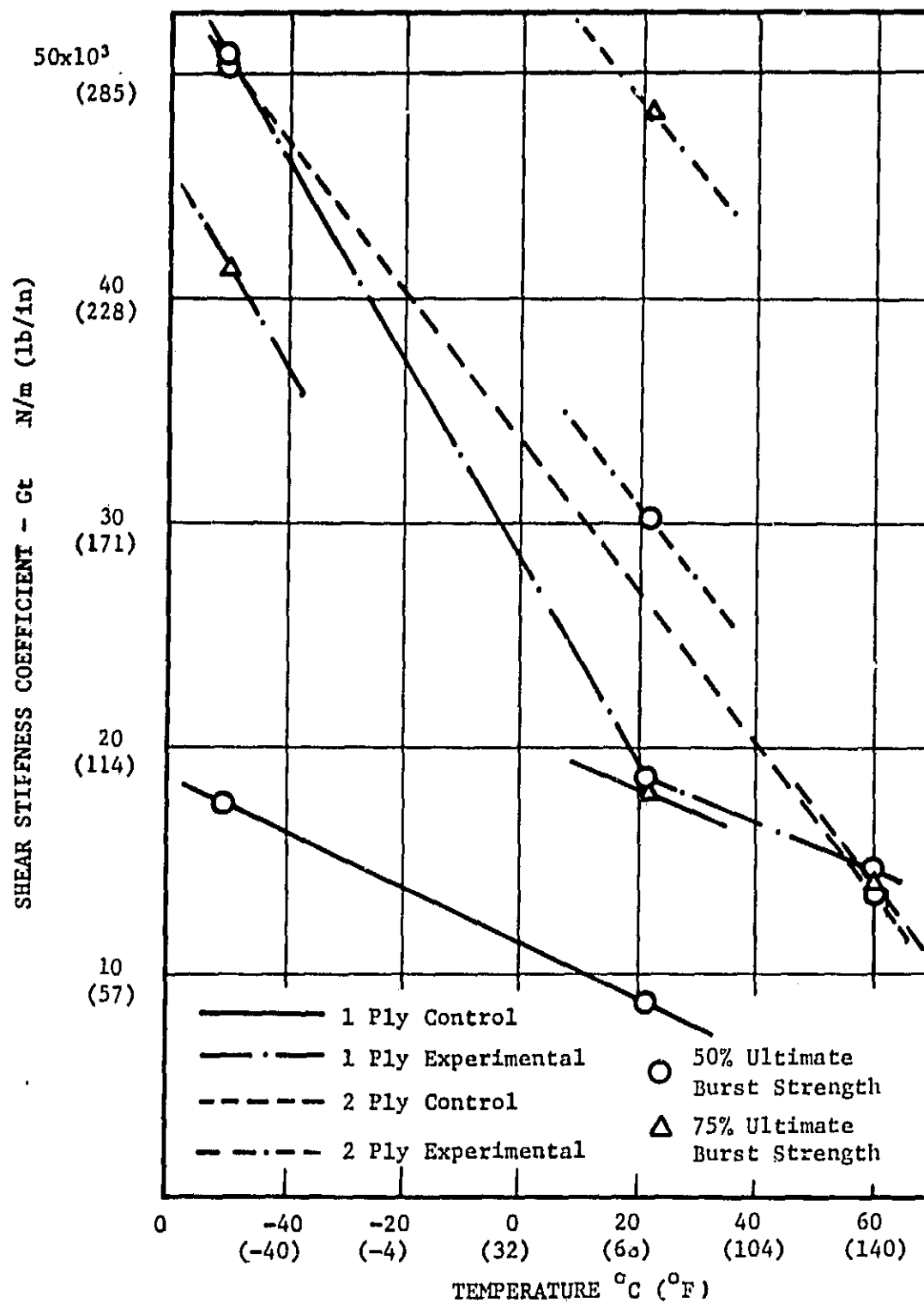
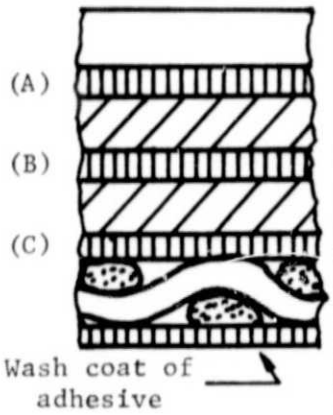


FIGURE 26: VARIATION OF SHEAR STIFFNESS COEFFICIENT WITH TEMPERATURE FOR BIAxIAL LOAD COMBINATION  $P_X/P_Y=2$  (Shear stiffness coefficient is assumed to be independent of shear load.)

TABLE 3

## PEEL STRENGTH FOR 1-PLY LAMINATES

All Data Are Mean Values of 5 Specimens Peeled Along The Machine Direction  
Newtons/Meter (Pounds/Inch)

Interface * (See Inset)	Control Laminate	Experimental Laminate
A (dry)	403 (2.3)	432 (2.5)
B (dry)	315 (1.8)	380 (2.2)
C <u>Before wash coat</u> (dry)	2420 (13.8)	1720 (9.8)
(wet)	1960 (11.2)	530 (3.0)
C <u>After wash coat</u> (dry)	2190 (12.5)	1500 (8.6)
(wet)	1750 (10.0)	1120 (6.4)
 <p>(A)</p> <p>(B)</p> <p>(C)</p> <p>Wash coat of adhesive</p>	<p>(Tedlar)</p> <p>(Mylar)</p> <p>(Mylar)</p> <p>(Dacron)</p>	<p>(Tedlar)</p> <p>(Mylar)</p> <p>(Mylar)</p> <p>(Kevlar)</p>

\*"Wet" refers to 72 hour H<sub>2</sub>O immersion before testing

2

Wash coat of adhesive was applied to fabric side as a separate operation

(Table 1) may account for some of the difference since the adhesive flow around the yarns would be greater than for the more tightly woven Kevlar. Interface C for Kevlar appears to be more sensitive to water than for Dacron since the addition of the wash coat to the otherwise exposed Kevlar fabric significantly reduced the effect of the water immersion.

#### 4.2 Durability Test Results

Test data for crease effects, abrasion, blocking, tear, and flexibility relate to performance of the materials under handling, packaging, and wear in service.

4.2.1 Crease tests.— The crease test data presented in Table 4 shows significant degradation of the experimental single ply fabric strength from folding and a slight decrease in observed strength for each of the two ply materials when compared with the data in Table 2. This may be due to the fact that the Kevlar has a very low elongation at failure (4 percent). This phenomena was not observed in the single ply control material because the Dacron has a lower modulus and much larger allowable elongation to failure. For the coated two ply fabric, the minimum attainable bend radius is several times that of the single ply fabric. Strength loss from folding appears to be one of the shortcomings of Kevlar which could be minimized by further development. Use of a more ductile gas barrier than Mylar film or positioning the Kevlar more closely to the neutral axis of the composite to increase the effective radius of bend would decrease fold damage. Alternative weave patterns could be employed to enhance the strength retained after creasing. Although crease sensitivity is an undesirable feature for inflatable materials applications, the increased strength to weight ratio offered by Kevlar composites may justify refined handling and packaging techniques that use mandrels and liners to control minimum bend radii.

4.2.2 Abrasion test data.— The number of cycles required to expose the fabric by erosion of the film or coating on the outward side of the materials when abraided against themselves was:

1-Ply Control	40,000 cycles
1-Ply Experimental	69,000 cycles
2-Ply Control	21,000 cycles
2-Ply Experimental	21,000 cycles

The superior abrasion resistance of the Tedlar film on the exterior of the laminates is primarily responsible for their greater abrasion life. Wear effects on the Tedlar were not visually evident for the first 15,000 to 20,000 cycles. The difference in abrasion life between Dacron and Kevlar fabric is probably due to the difference in yarn size and count. Since wear begins at the points of greatest pressure, where yarns in the fabric cross, the coarse weave Dacron concentrated the wear on a smaller area than the finer weave Kevlar fabric.

TABLE 4

## UNIAXIAL TENSILE STRENGTH AFTER 180° CREASING

SINGLE PLY MATERIALS			BIAS PLY MATERIALS		
Control 1 Ply Laminate		Experimental 1 Ply Laminate	Control 2 Ply Coated		Experimental 2 Ply Coated
$\frac{N}{m}$	$\frac{lb}{in}$	$\frac{N}{m}$ $\frac{lb}{in}$	$\frac{N}{m}$	$\frac{lb}{in}$	$\frac{N}{m}$ $\frac{lb}{in}$
47,950	274	34,650   198	32,550	186	67,200   384
47,950	274	29,750   170	32,900	188	67,550   386
47,950	274	36,050   206	29,750	170	67,900   388
49,000	280	35,525   203	30,275	173	53,375   305
<u>49,700</u>	<u>284</u>	<u>30,450</u> <u>174</u>	<u>30,275</u>	<u>173</u>	<u>70,350</u> <u>402</u>
Avg. 48,510	277	33,285   190	31,150	178	65,275   373

4.2.3 Blocking test data.- No blocking was observed for either the control or the experimental laminate. Blocking is not expected to be a problem with materials of this type unless major changes in the adhesive or coatings are made. Since blocking forces were lower than the measurement threshold (10 mg.), no quantitative results are recorded for these tests. The material samples used in the blocking tests were unlubricated (unstarched, unpowdered).

To maintain control over the blocking tendency of polymeric materials, explicit curing and storage conditions are prescribed. The laminates tested were stored at 40°C (100°F) for 48 hours to cure the film-to-film bonds and for 72 hours to cure the film-to-fabric bond.

4.2.4 Tear test data.- Trapezoidal tear test results are presented in Table 5. As expected, the single ply control exhibited the best tear resistance. The experimental single ply fabric yielded values nearer to those of the control two ply fabric due to the tight weave and the small yarn size which reduces the ability of the fabric to withstand the load at the tear root.

The tear resistance of the experimental two ply fabric appears to be better than either of the experimental single ply or the control two ply, as may be expected, since the uniaxial tensile strength is nearly twice that of either the control or single ply experimental materials. In general, coated materials do not provide as much tear resistance as laminated materials since open weave, high denier fabrics having high inherent tear strength cannot be used in the former because of coating strike-through.

Except for fill direction tears in the coated fabrics, all tears occurred by progressive fracture of successive yarns in the fabric. For most of the fill direction tears in the coated material, the fabric plies separated without yarn fracture.

No criteria have been established for minimum tear resistance of tethered balloon envelopes. Standards for single wall, air supported buildings based on a ten-year study of about 900 structures indicates the minimum trapezoidal tear resistance of a cylindrical structure subject to aerodynamic loading should be directly proportional to the diameter (Reference 5). For example, the minimum trapezoidal tear strength for a 15-meter (45<sub>2</sub> foot) diameter structure would be 95N (21 lbs) when operated at 250 N/m<sup>2</sup> (1 inch H<sub>2</sub>O) internal pressure in winds up to 33 m/s (65 knots).

4.2.5 Flex test data.- At 1000 cycles on the Bally Flexometer, the single ply control laminate showed severe failure of the film gas barrier by cracking and delamination. At 3000 cycles, the single ply experimental laminate began to exhibit small pinholes. At 4200 cycles, failure of the experimental laminate had proceeded to the same level as the control laminate at 1000 cycles, and both laminate specimens showed broken yarns. The two ply coated fabrics showed delamination at about 24,000 cycles with the experimental, Kevlar material having the more extensive failure.

Since the adhesive Mylar and Tedlar films used in the lamination have from 2 to 5 times the tensile stiffness of the urethane and neoprene coatings

TABLE 5

## TRAPEZOIDAL TEAR TEST DATA

SINGLE PLY MATERIALS				TWO PLY MATERIALS			
Control		Experimental		Control		Experimental	
Warp N (lb)	Fill N (lb)	Warp N (lb)	Fill N (lb)	Warp N (lb)	Fill N (lb)	Warp N (lb)	Fill N (lb)
169 (38)	209 (47)	62 (14)	40 (9)	49 (11)	*	85 (19)	94 (21)
169 (38)	196 (44)	58 (13)	33 (7.5)	53 (12)	*	87 (19.5)	107 (24)
156 (35)	200 (45)	56 (12.5)	33 (7.5)	58 (13)	*	100 (22.5)	*
169 (38)	227 (51)	58 (13)	33 (7.5)	49 (11)	*	87 (19.5)	*
174 (39)	214 (48)	56 (12.5)	36 (8.0)	53 (12)	*	104 (23.5)	*
Avg. 167 (38)	209 (47)	58 (13)	35 (7.9)	53 (12)	*	93 (21)	100 (23)

\*No Tear Value -  
Ply Delamination



used in the two ply materials, the above results are not surprising. High flex life is an advantage in applications where an inflatable structure must be deflated and repackaged a large number of times or where the structure must be handled by relatively unskilled personnel.

#### 4.3 Geometric and Mechanical Properties

4.3.1 Helium permeability.— Helium permeability data are presented in Table 6. The laminate materials had a lower permeability than the coated fabrics. Pinholes in the outer layer of coated materials allow helium to flow along yarn filaments of the fabric and through pinholes in the additional layers of coating. The two layers of Mylar film bonded with adhesive prevent lateral flow of any helium passing through one layer of film. The two to one ratio of permeability between the film laminates the coated materials and is typical for these materials. Permeability of creased or multi-cycle stressed material samples generally show significant increases over virgin materials. Typical permeability acceptance levels for balloon materials are one to two liters per square meter per 24 hours on unstressed, uncreased material samples.

TABLE 6

##### HELIUM PERMEABILITY TEST DATA

(1/m<sup>2</sup>/24 hr at 300 N/m<sup>2</sup> pressure)

Single-Ply Materials		Two-Ply Materials	
Control	Experimental	Control	Experimental
	0.3	0.6	0.4
0.3-0.5	0.4	0.8	0.6
	<u>0.3</u>	<u>0.7</u>	<u>0.5</u>
Avg. 0.4	0.3	0.7	0.5

4.3.2 Constituent weights.— Finished weights of the experimental and control composites and the breakdown of constituent weights are given in Table 7.

To put the weight information into more meaningful terms, aerostats normally use materials in the range of .02 kg/m<sup>2</sup> (3 oz/yd<sup>2</sup>) to .408 kg/m<sup>2</sup> (12 oz/yd<sup>2</sup>) because of strength requirements and currently achievable strength to weight ratios.

Further development with Kevlar based materials may achieve material of .102 kg/m<sup>2</sup> (3 oz/yd<sup>2</sup>) and 26,250 N/M (150 lb/in) strength which corresponds to current materials weighing .408 kg/m<sup>2</sup> (12 oz/yd<sup>2</sup>). The two experimental

materials represent the strength-to-weight improvement that was a major objective of this contractual effort. The objective for the laminated material was to reduce weight while maintaining the same strength as conventional materials, 43 kN/m (250 lbs/in) for .203 kg/m<sup>2</sup> (6 oz/yd<sup>2</sup>). The objective for the coated materials was to achieve greater strength for conventional weight, 70 kN/m (400 lbs/in) for .406 kg/m<sup>2</sup> (12 oz/yd<sup>2</sup>). The data in Table 8 indicate that these objectives have been achieved.

TABLE 7

ANALYSIS OF CONSTITUENT WEIGHTS

	Controls		Experimental Materials	
	Constituent	kg/m <sup>2</sup> (oz/yd <sup>2</sup> )	Constituent	kg/m <sup>2</sup> (oz/yd <sup>2</sup> )
Laminated Materials	Tedlar	.064 (1.89)	Tedlar	.064 (1.89)
	Adhesive	.007 (0.20)	Adhesive	.007 (0.20)
	Mylar	.008 (0.25)	Mylar	.008 (0.25)
	Adhesive	.005 (0.15)	Adhesive	.005 (0.15)
	Mylar	.008 (0.25)	Mylar	.008 (0.25)
	Adhesive	.040 (1.17)	Adhesive	.040 (1.17)
	Dacron	.129 (3.8)	Kevlar	.064 (1.89)
	Adhesive	<u>.010 (0.29)</u>	Adhesive	<u>.010 (0.29)</u>
	TOTAL	.271 (8.00)	TOTAL	.206 (6.09)
Coated Materials	Hypalon	.068 (2.0)	Hypalon	.068 (2.0)
	Urethane	.085 (2.5)	Urethane	.085 (2.5)
	Dacron	.065 (1.9)	Dacron	.048 (1.4)
	Neoprene	.119 (3.5)	Neoprene	.119 (3.5)
	Dacron	<u>.119 (3.5)</u>	Kevlar	<u>.092 (2.7)</u>
	TOTAL	.456 (13.4)	TOTAL	.412 (12.1)

4.4 Other Characteristics

The materials described were not analyzed for creep and relaxation effects or such thermal and electrical characteristics as absorptivity, emissivity, reflectivity, transmissibility, heat capacity, conductivity, dielectric strength, outgassing and vapor conductivity.

## 5.0 SUMMARY AND CONCLUDING REMARKS

Two composite, sheet materials for use in inflatable structures using fabric of the new DuPont organic fiber "Kevlar" have been designed, manufactured in "pilot" scale quantities and tested. Two conventional materials, similar to the above, except for the use of Dacron fabric in place of Kevlar were produced and tested as experimental controls. One pair of control and experimental materials was produced by adhesive lamination of film and fabric plys. The other pair of materials was produced by coating fabrics with various elastomeric substances (Table 1). Laminated materials contained a single ply of square weave fabric. Coated materials each had two plys of square weave fabric oriented at 45 degrees to each other for improved dimensional stability.

Lamination of the single ply of Kevlar fabric to film gas barriers presented no unusual difficulties. The tensile stiffness of the fabric produced a firm, stable web on process machinery.

Assembly of the coated Kevlar ply and Dacron bias ply on standard, coating equipment was complicated by the difference in elasticity between the Kevlar aligned with the machine direction and the Dacron fabric tensioned on the bias. The automatic guiding equipment used to align the plys was not sufficiently sensitive to prevent fabric wrinkles which were set in place when the plys were bonded together.

The four materials were tested for tensile and shear strength, tear, abrasion, crease and flex resistance, blocking and permeability. Mean values of representative properties are given in Table 8.

Comparing corresponding control and experimental materials indicates the effect of replacing Dacron fabric with Kevlar. Tensile and shear break strengths were increased by about one-third for the one ply laminates and were more than doubled for the two ply coated materials. Tensile stiffness was increased about three fold for one ply and ten fold for the two ply materials. Shear stiffness of the one ply materials was doubled.

The one ply, Kevlar laminate exhibited considerable strength loss after creasing. The coated Kevlar material was much less affected by the same treatment. Relocation of the Kevlar fabric nearer the neutral plane of the laminate would probably reduce the effect of creasing.

Trapezoidal tear strength tended to vary as the strength of individual yarns. The one ply, Dacron laminate had yarns more than twice as strong as the Kevlar yarns used in the corresponding laminate. The size of Kevlar yarn used was determined in this case by availability. For the coated fabrics, yarn size is generally determined by the allowable fabric weight and space between yarns. Any appreciable opening between yarns in a fabric to be coated allows the coating material to bleed through, which interferes with the coating operation on the reverse side. Within these constraints, tear strength can be increased by

TABLE 8

## SUMMARY OF CHARACTERISTICS OF CONTROL AND EXPERIMENTAL MATERIALS

Metric Units (English Units)

CHARACTERISTIC	CONTROL		EXPERIMENTAL	
	1-Ply Laminate	2-Ply Coated	1-Ply Laminate	2-Ply Coated
WEIGHT - $\text{kg/m}^2$ (oz/yd <sup>2</sup> )	0.271 (8.0)	0.456 (13.4)	0.206 (6.09)	0.412 (12.1)
TENSILE STRENGTH $P_Y$ , @ 22°C (72°F) N/m (lbs/in)	46 (262)	32 (184)	47 (269)	69 (394)
	$P_Y/P_X=0$ $P_Y/P_X=2$	26 (148)	35 (200)	50 (285)
SHEAR STRENGTH, $P_{XY}$ @ 22°C (72°F), $P_Y/P_X=2$ N/m (lbs/in)	3.2 (18)	3.9 (22)	3.3 (19)	9.5 (54)
TENSILE STRENGTH LOSS AFTER CREASING - %	0.	3	29	5
TRAPEZOIDAL TEAR STRENGTH - N(lb)	167 (38)	53 (12)	58 (13)	93 (21)
	Warp Fill	Ply delamination	35 (8)	100 (23)
ABRASION RESISTANCE Cycles to Failure	40,000	21,000	69,000	21,000
FLEX LIFE - Cycles to Failure	1,000	24,000	3,000	24,000
BLOCKING - mg	<10	<10	<10	<10
PERMEABILITY - $1/\text{m}^2/24 \text{ hrs}$	0.4	0.7	0.3	0.5

increasing the size and spacing of the yarns.

The Tedlar PVF film on the laminates exhibited about twice the abrasion resistance of the elastomeric coatings on the two ply materials. However, the coated materials' resistance to repeated flexure was about an order of magnitude better than that of the laminates. Flex life of the laminates could probably be improved by relocating the fabric near to the neutral plane and by substituting a more ductile film such as Hytrel\* or Saran\*\* for the Mylar gas barrier.

Permeability levels for all materials were well within the usual limits specified for tethered aerostats. The film laminates showed about half the permeation rate of the coated materials.

The processing difficulties described do not present a serious obstacle to the manufacture of Kevlar-based composites. The bias ply fabric could be replaced or obviated by use of a multiaxial yarn construction such as triaxially woven fabric or parallel, non-woven yarn arrays like those widely used for reinforcing polyethylene tarpaulins and vapor barriers for building construction.

The reduction in resistance to handling (creasing, flexing) from the Dacron based materials to the Kevlar materials is attributed to the high modulus of the Kevlar fibers and to the high film moduli in the case of the laminates. Although these characteristics are undesirable for inflatable structures, the improved strength to weight ratios offered by Kevlar composites may justify more complex handling and packaging techniques for flexible structures incorporating Kevlar filaments.

The prime objective for the experimental laminate was to reduce weight while maintaining the same strength as in conventional counterparts. The prime objective for the experimental coated materials was to obtain greater strength for the same weight. The test program reported in this paper indicates that these objectives have been achieved.

\*DuPont Trademark

\*\*Dow Chemical Trademark

## REFERENCES

1. Niccum, R. J., "Comparison of Polyester, Film-Yarn Composite, Balloon Materials Subjected to Shear and Biaxial Loading," NASA Contractor Report CR-2047, June, 1972.
2. Alley, V. L., Jr., and Faison, R. W., "Experimental Investigation of Strains in Fabric Under Biaxial and Shear Forces," Journal of Aircraft Vol. A, No. 1, January, 1972, pp. 55-60, by the American Institute of Aeronautics and Astronautics.
3. ASTM Method D 1876.
4. Federal Test Method 5136.
5. "Minimum Performance Standard for Single-Wall Air-Supported Structures," March, 1971, by Air Structures Division of Canvas Products Assn., International.

APPENDIX A  
Peel Test Methods for Laminates

1.0 Scope

- 1.1 This specification details a method for determining the relative resistance to delamination and/or bond strengths of laminates and tapes.

2.0 Equipment

The following equipment and apparatus are required in order to test all methods of this specification:

Instron testing machine

Rotary drum, 5" diameter x 3" wide

Hand sealing iron

Pressure sensitive double backed masking tape, 3M No. 40<sup>0</sup>

Thwing-Albert 1" Precision sample cutter

Scissors

3.0 General Comments

- . Peel values are not an absolute yard stick as to how well the material will serve its intended purpose.
- . Peel results will vary with the type of materials being tested, their angle's of separation, adhesive thickness, speeds of separation, adhesive type, etc.
- . A relatively rigid adhesive will tend to give test results that are artificially low since the stress will be concentrated in a narrow line at the point of separation. By contrast a ductile or elastic adhesive system, because it can elongate and distribute the force over a larger area, will appear much stronger in peel
- . Rigid adhesives generally require a large force to initiate peel and a small force to sustain peel.

4.0 Chart Interpretation and Recording

4.1 General

Unless otherwise specified, the minimum and maximum values of each test shall be recorded on the Laboratory Request form. A minimum of 3 specimens shall be tested for each location or direction. Each

set of readings shall be totaled and averaged to provide a minimum and maximum average bond strength. Interpretation of strip chart shall be in accordance with the following instructions. Readings shall be reported in lbs/inch, unless otherwise specified.

#### 4.2 Minimum, Average and Maximum Values

Most peels are reported as minimum bond. This can generally be described as an average of the 3 to 5 lowest points, disregarding spikes, on the chart (see Figure 1). The first  $\frac{1}{4}$ " and last  $\frac{1}{4}$ " of peel shall be excluded for purposes of obtaining the peel value.

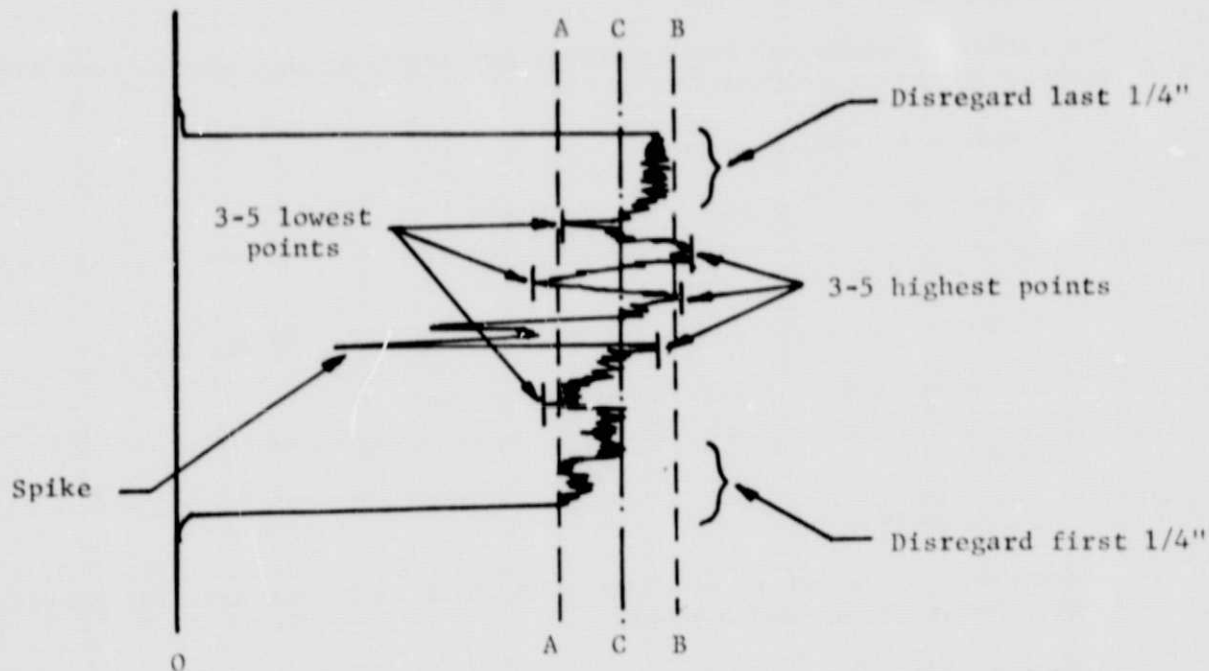


FIGURE 1

A = Minimum bond value. Note that the extreme spike is not to be included as it is not truly representative.

B = The maximum bond value (average of 3 to 5 highest points).

C = Mean value or average load value.

NOTE: Generally the arithmetic average of the minimum and maximum bond values should approximate the actual average load value from the chart.

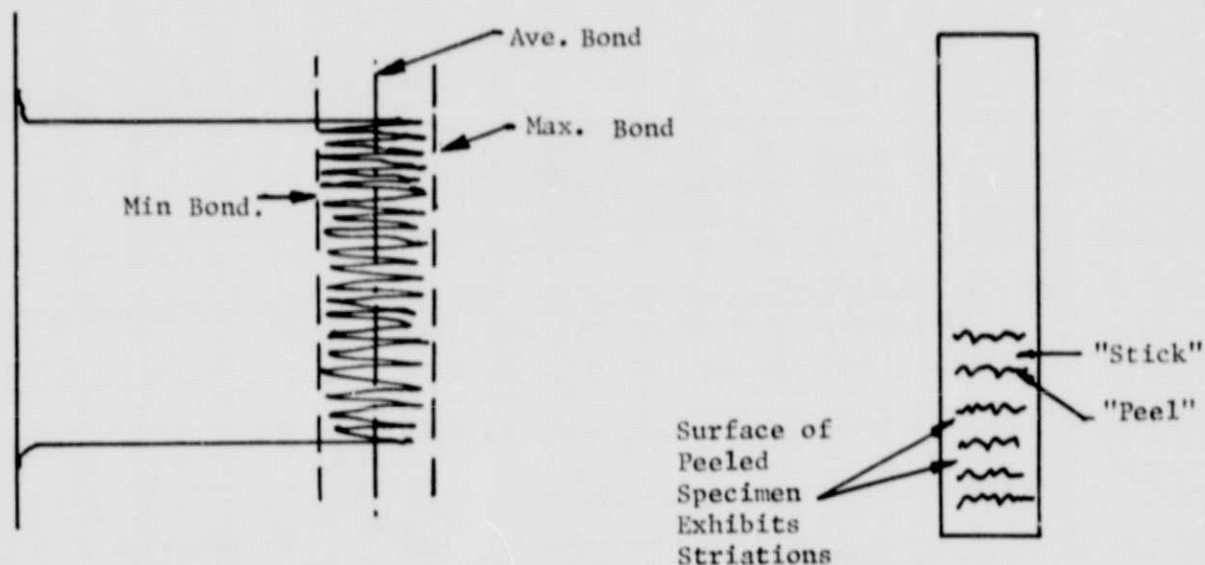


#### 4.3 Extreme Low Values

Low extreme spikes are normally discarded unless they represent the true condition of the material. In some cases they will be representative.

#### 4.4 Cyclic Peel

Certain adhesive systems will produce a cyclic trace on the chart like the following:



In this event, read minimum and maximum bond values for general recording purposes and identify the peel as "cyclic peel".

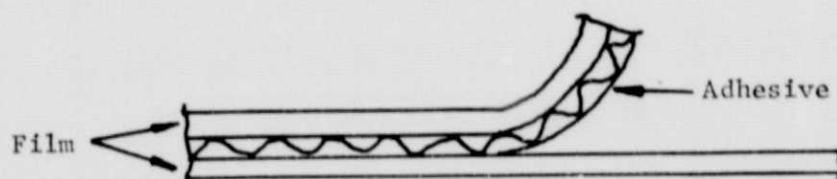
With a rigid adhesive system characterized by the above read out, it is recommended that the average load value be used because it is most representative of the true peel strength.

#### 4.5 Failure Mode

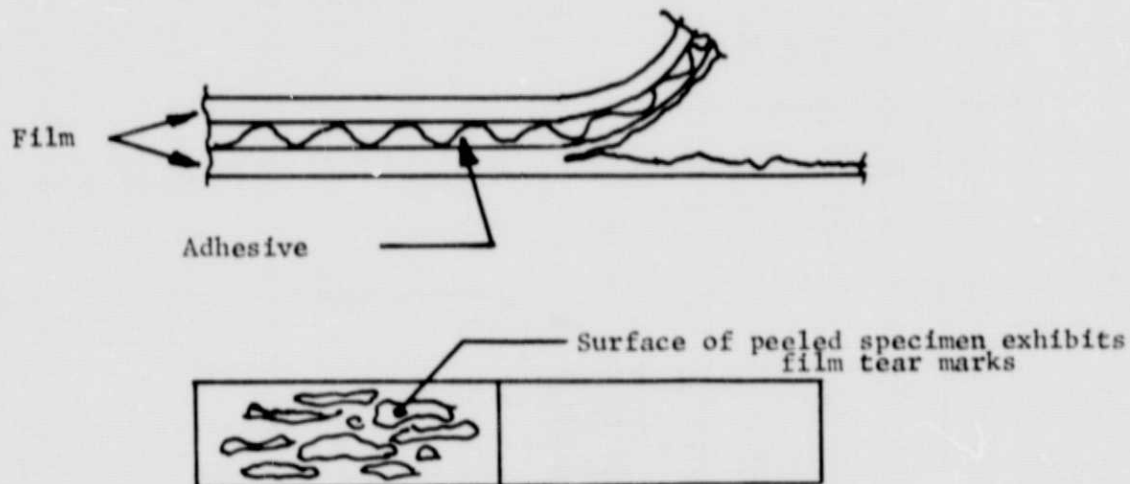
Ideally the peel test should separate the adherends by splitting the adhesive layer (cohesive failure) with part of the adhesive remaining on both substrates. In practice this seldom occurs. It is important that the failure mode be identified and recorded during peel testing.

Failure modes may be one of or a combination of the following:

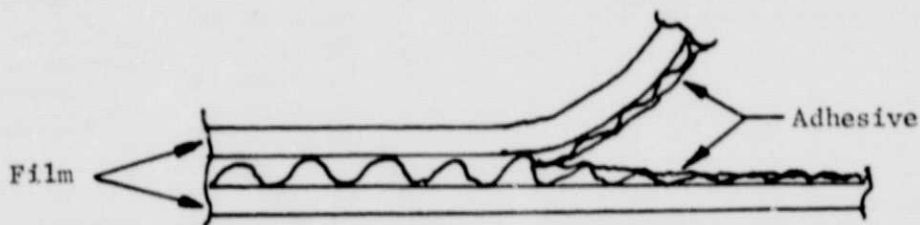
AF = Adhesion failure. Adhesive will stay entirely with one adherend.



CS = Cohesive failure of substrate. Experience is required to distinguish this condition from that of adhesion failure.



CA = Cohesion failure of adhesive. Adhesive splits and leaves some adhesive on both metal foil and plastic film.



## 5.0 Conduct of Test

### 5.1 Sample Preparation

- (a) Cut on Thwing-Albert precision cutter.
- (b) Size - 1" x 12", to  $\pm 0.5\%$  accuracy.
- (c) Edges must not be nicked or marred in any manner.
- (d) Samples must be identified by number for each condition.

## 5.2 Test Procedure

- (a) Separate the adherends at the end of each sample using a pair of scissors and a hot hand iron.
- (b) Place a 2" wide strip of double backed pressure sensitive tape all around the drum. Fasten the drum into the lower jaw receptacle on the Instron cross head.
- (c) Press one side of the specimen onto the tape and clamp the other adherend into the upper jaw.
- (d) Set the Instron at the following conditions:
  - Crosshead travel: 2" per minute
  - Chart speed: 2" per minute
  - Full scale load switch at ten pounds
- (e) Peel sample for approximately one (1) minute so that 2" of the specimen is separated.
- (f) Read the minimum and maximum values from the chart and record values on the Laboratory Report Form.

## APPENDIX B

### Blocking Test for Laminates and Adhesive Coated Materials

#### 1.0 Scope

This specification describes the procedures to be used when testing the blocking of laminates and adhesive coated materials.

#### 2.0 Apparatus

2.1 Instron Testing Instrument

2.2 Controlled temperature chamber

2.3 Weights, 20 pound, 2" x 2" base

2.4 A press capable of exerting 5 psi at 130°F

#### 3.0 Procedure

3.1 Fold a 2" x 6" sample of the laminate to be tested (adhesive side in on the first fold) twice so that a 2" x 2" square is formed. See Figure 1. This procedure may be reversed for laminates with coating on the film side.

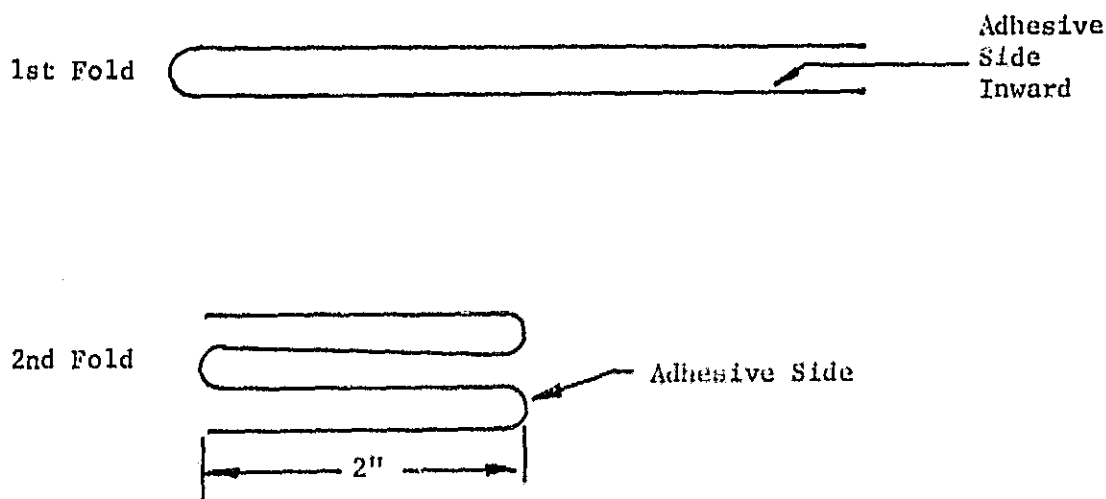


FIGURE 1

3.2 Place one weight (2.3) on the sample so that the weight covers the sample exactly. Condition one sample under weight for 24 hours at room temperature and another at 160°F.

3.3 After 24 hours, place the sample in the Instron as shown in Figure 2. Be careful not to pull the center fold open.

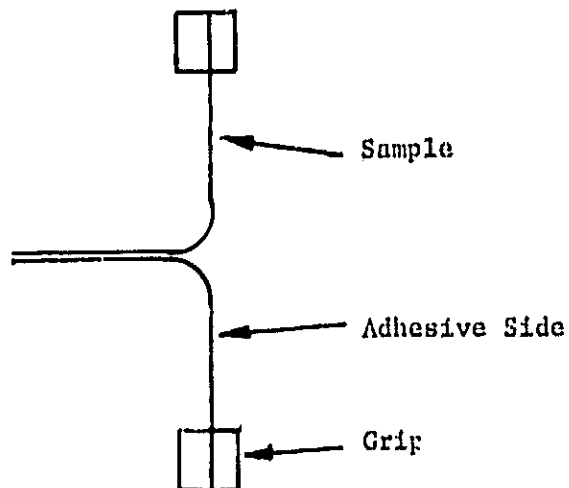


FIGURE 2

3.4 Set the Instron as follows:

Crosshead:	1.0 in/min.
Chart speed:	1.0 in/min.
Jaw spread:	2 inches

3.5 Start the crosshead and chart. Record the average peeling force on the test request form.

3.6 Acceptance Criteria for Laminates

3.6.1 For open scrim laminates failure will be described as blocking sufficient to make a hole in the film barrier.

3.6.2 For cloth laminates the maximum tolerable peel force must be specified on the test request form.